

Fig. 1

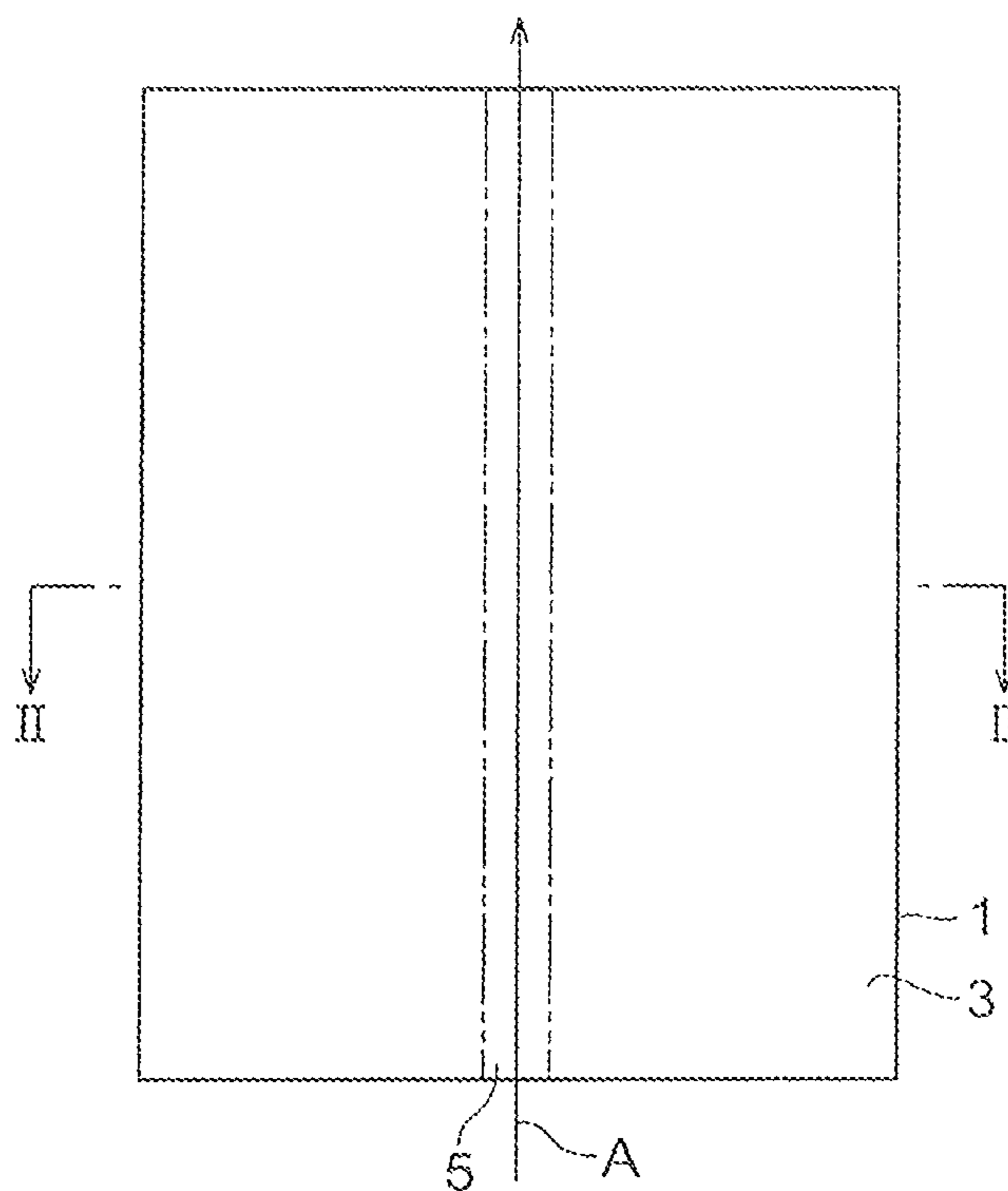


Fig. 2

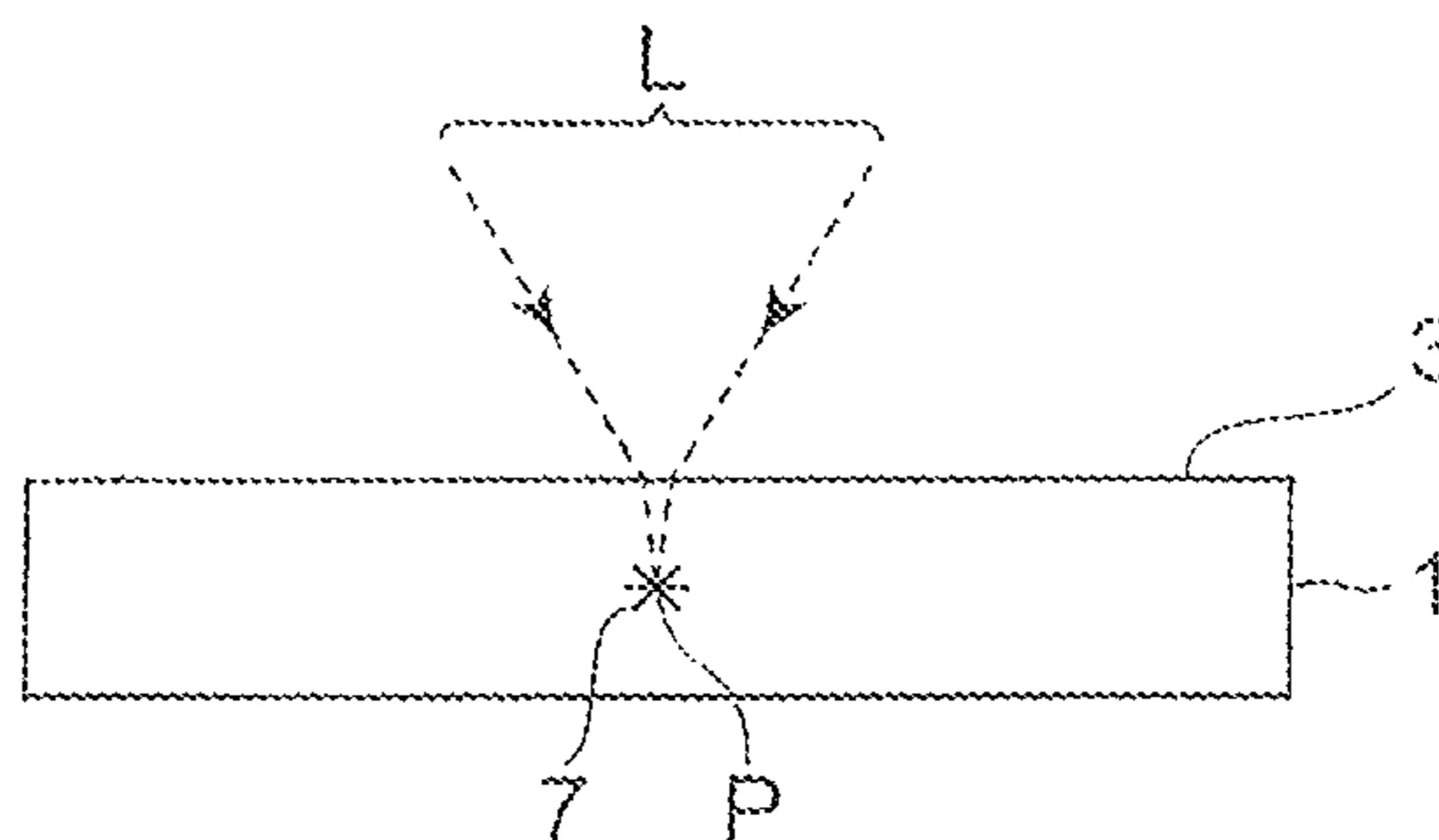


Fig. 3

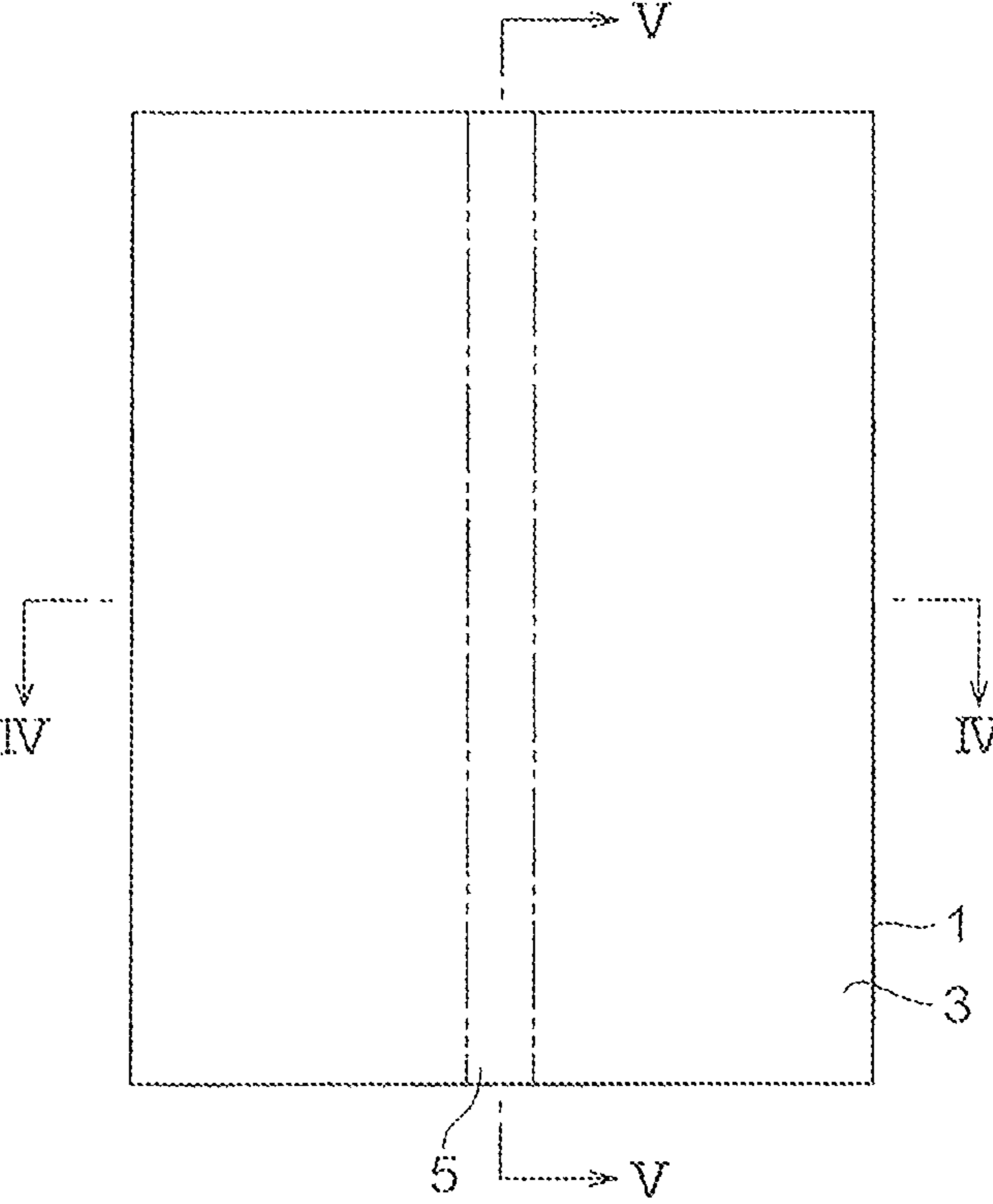


Fig. 4

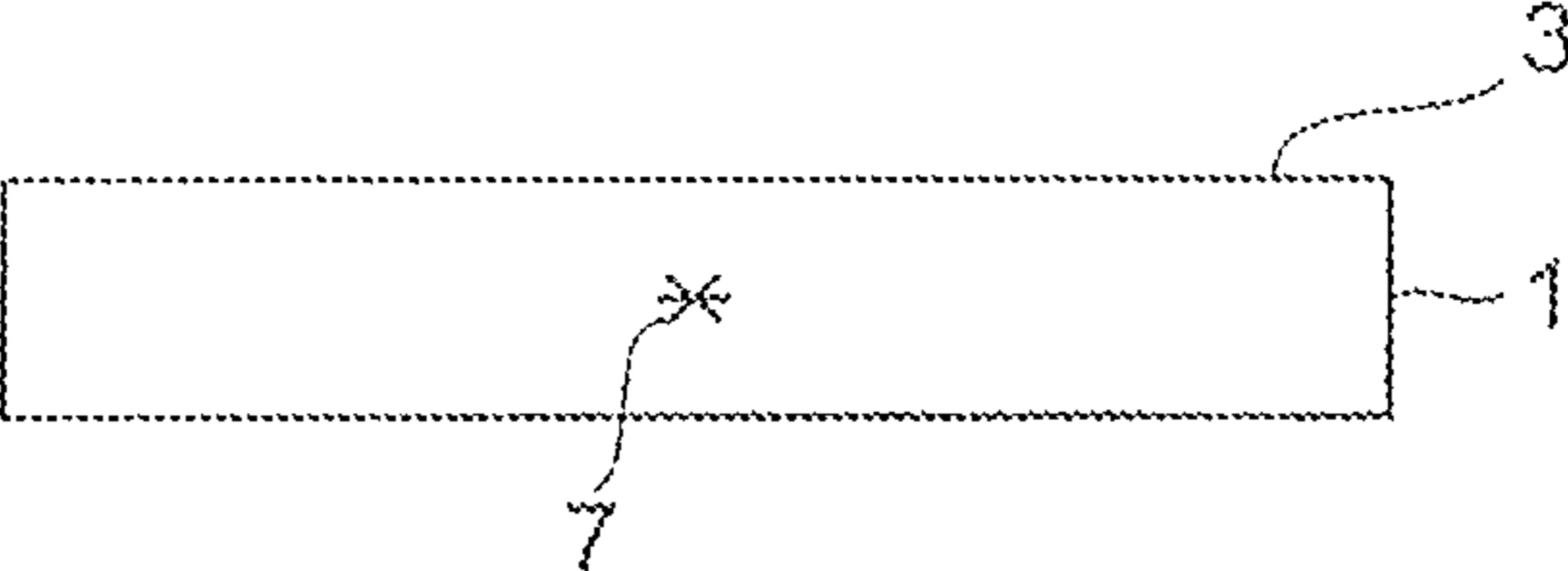


Fig. 5

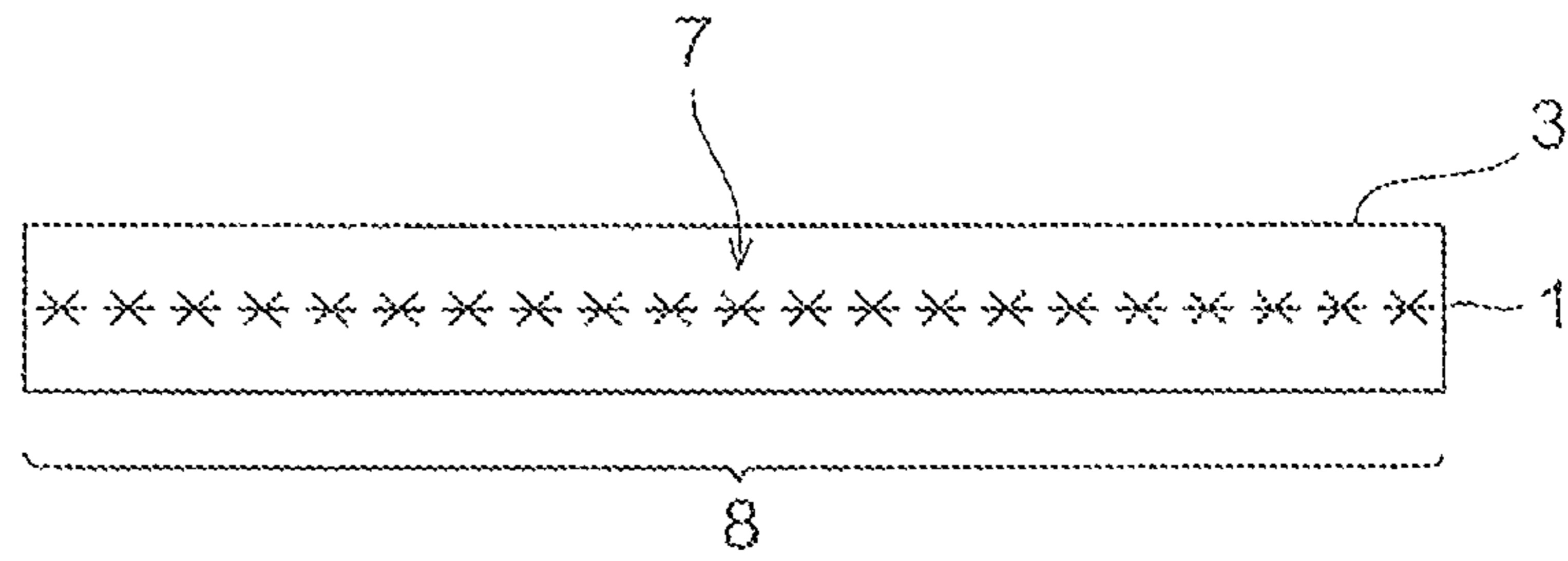
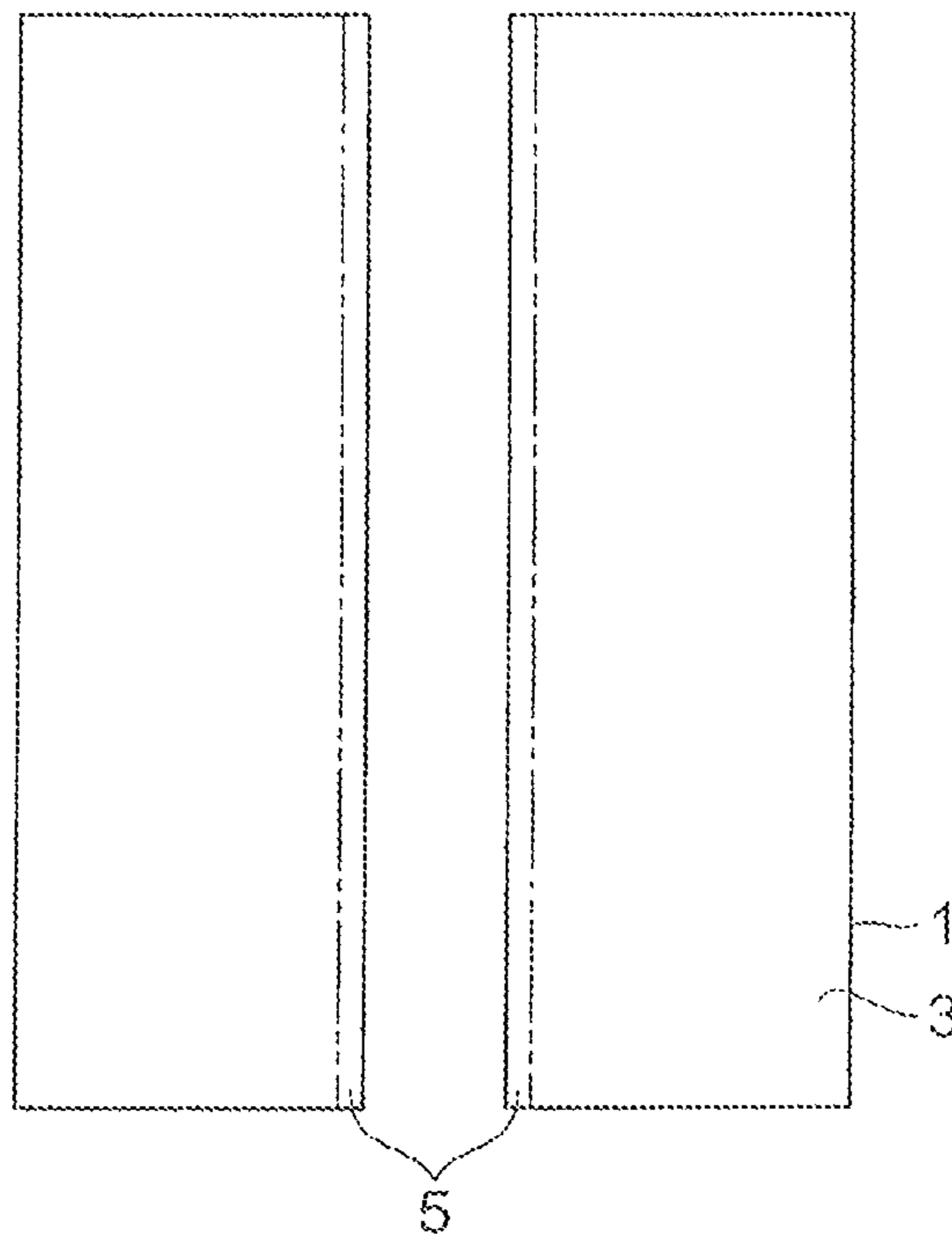


Fig. 6



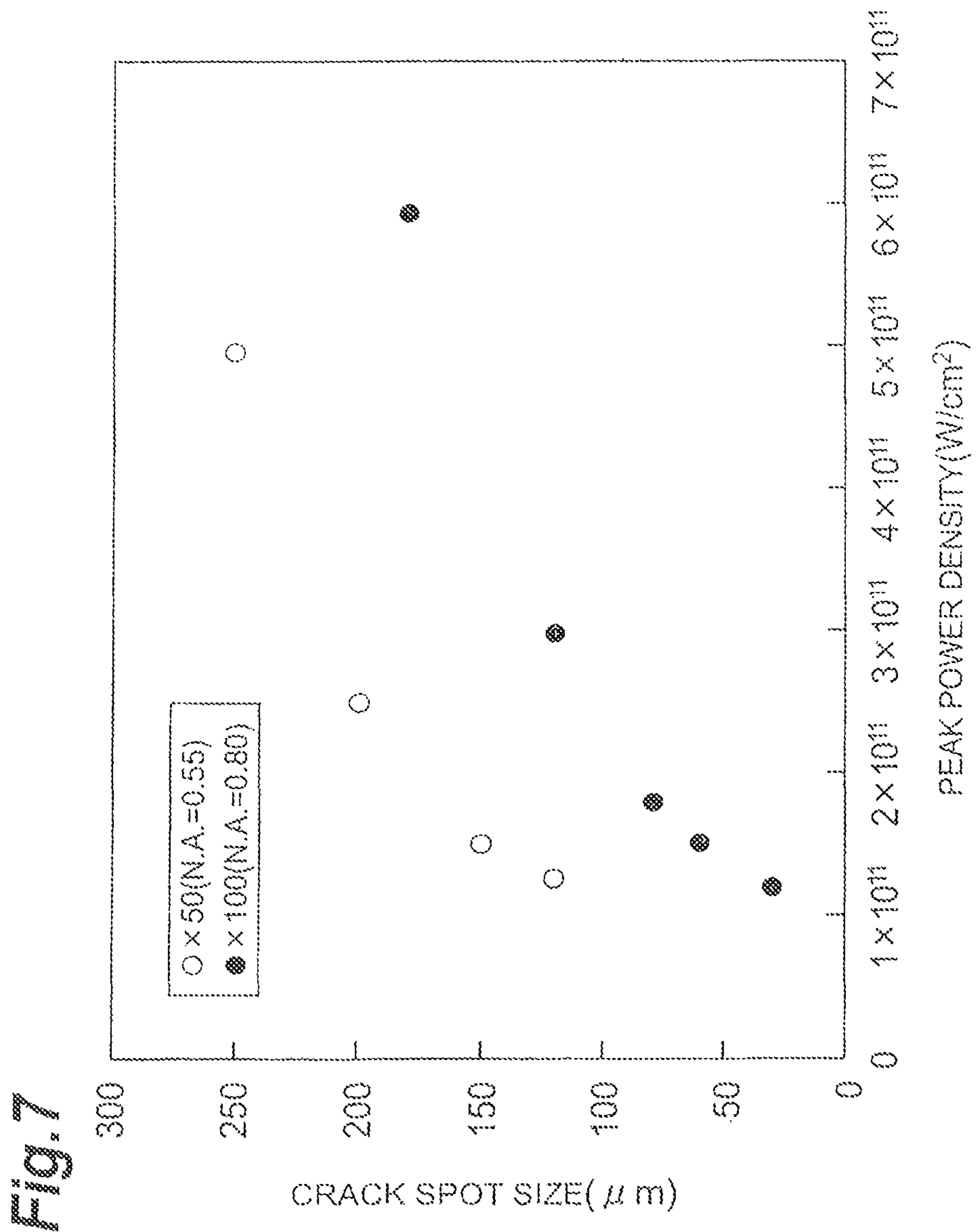


Fig. 8

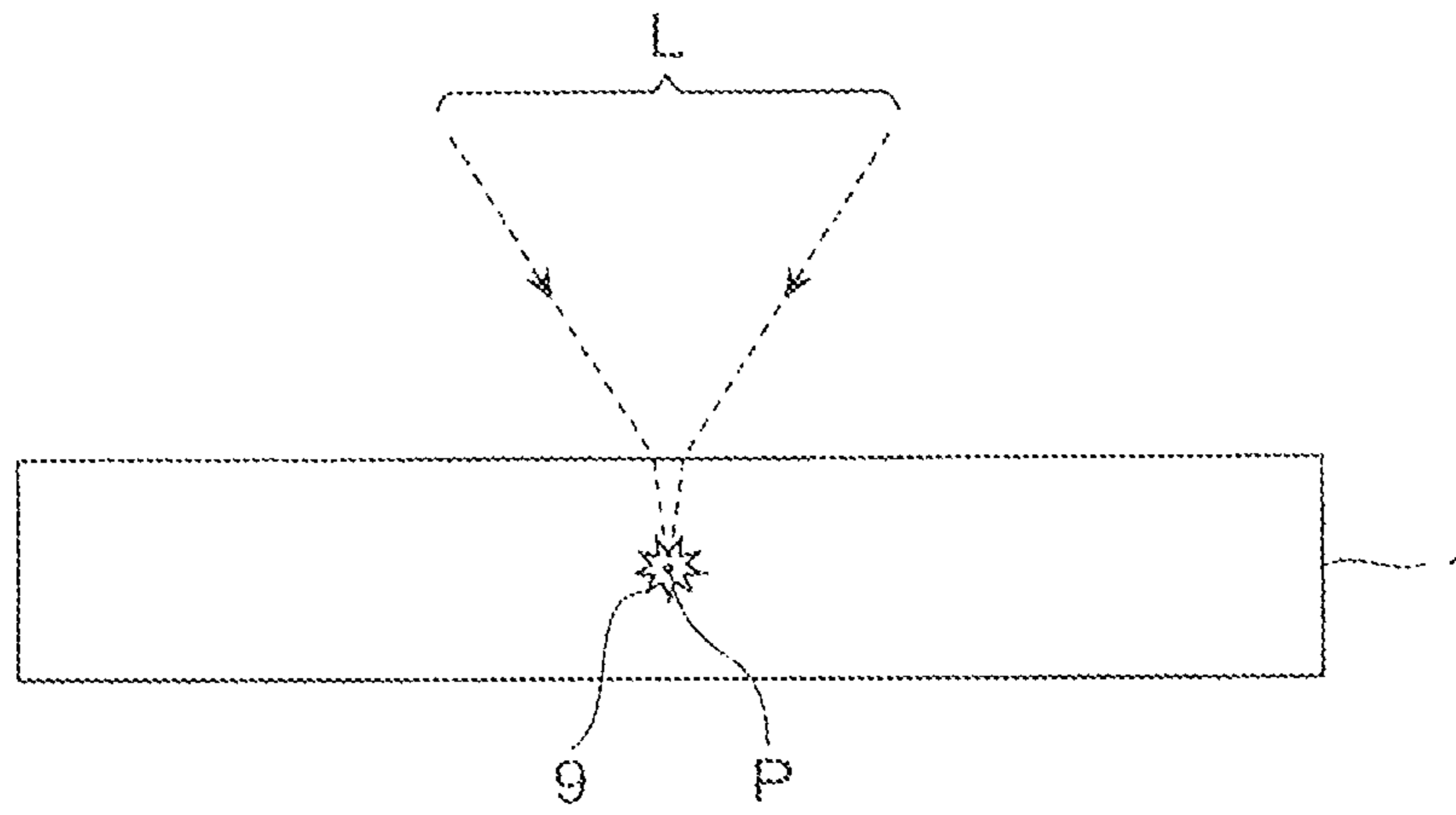


Fig. 9

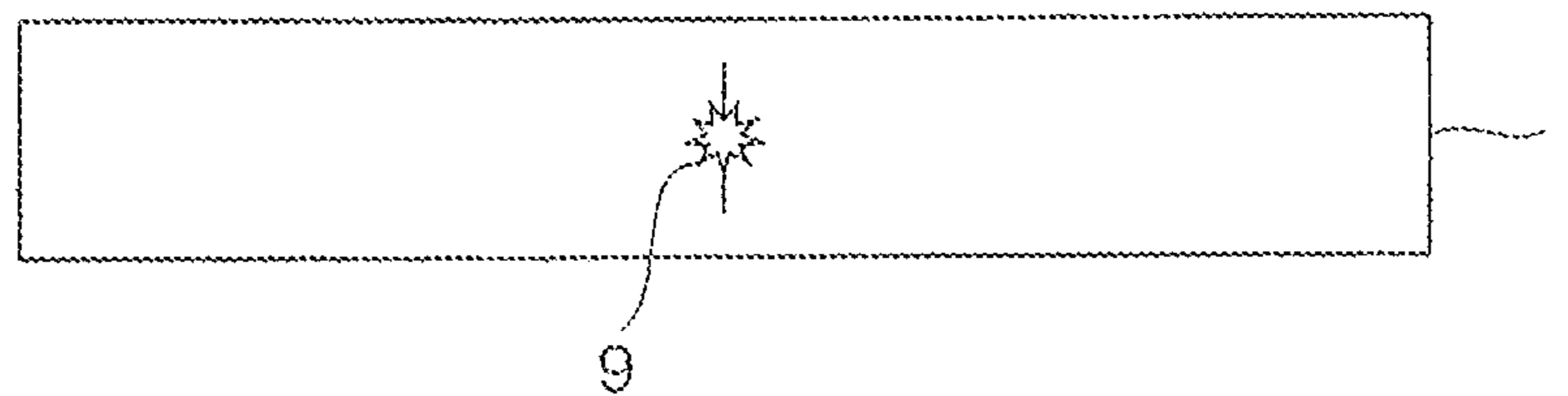


Fig. 10

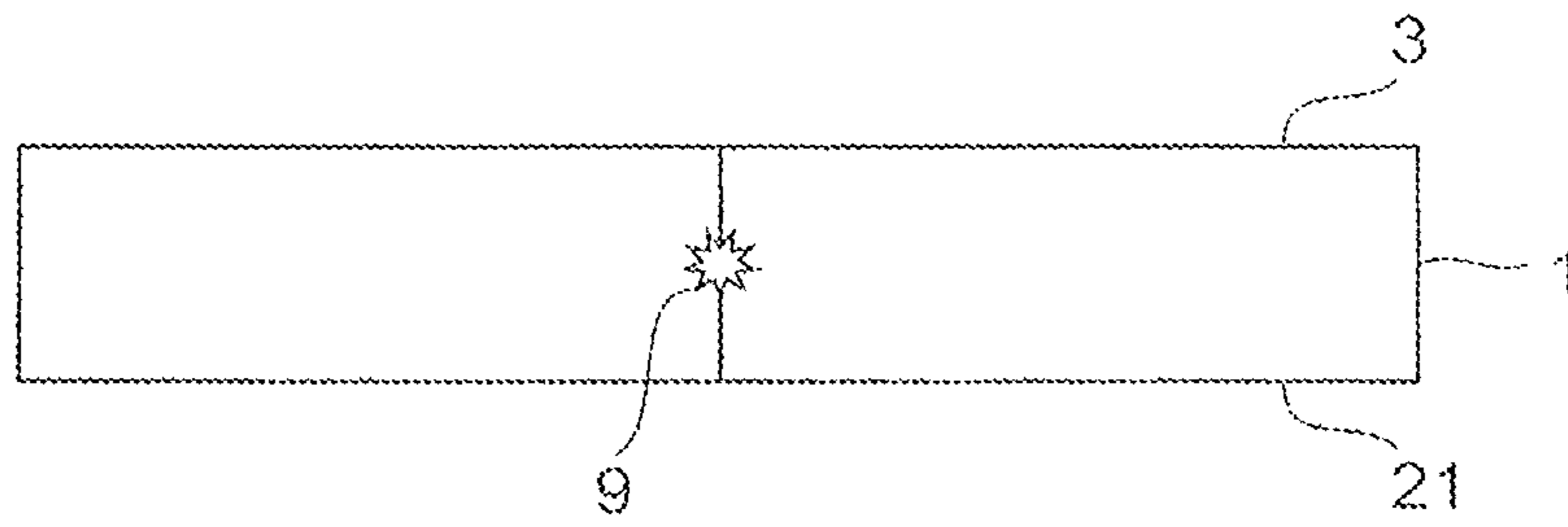
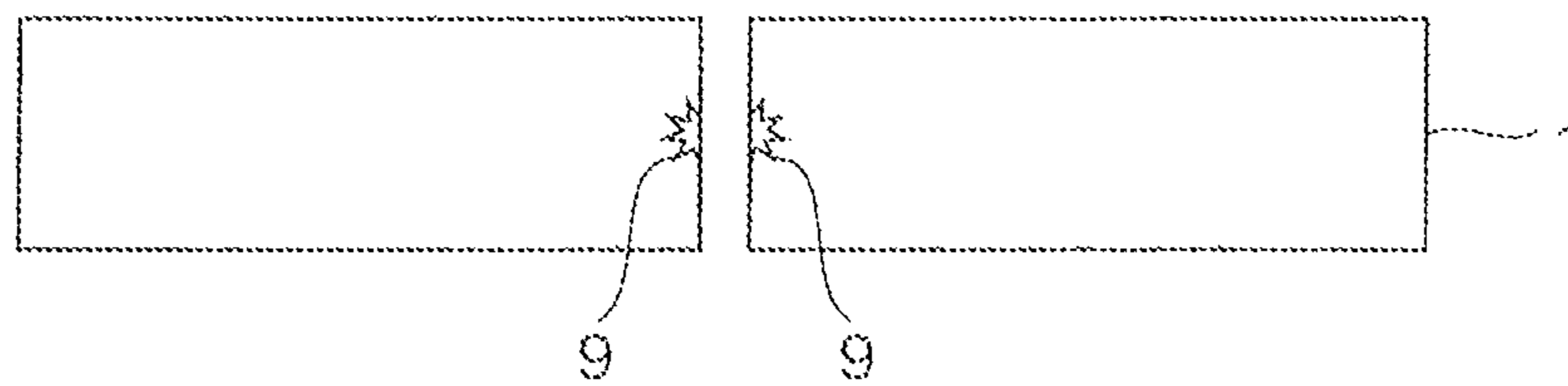


Fig. 11



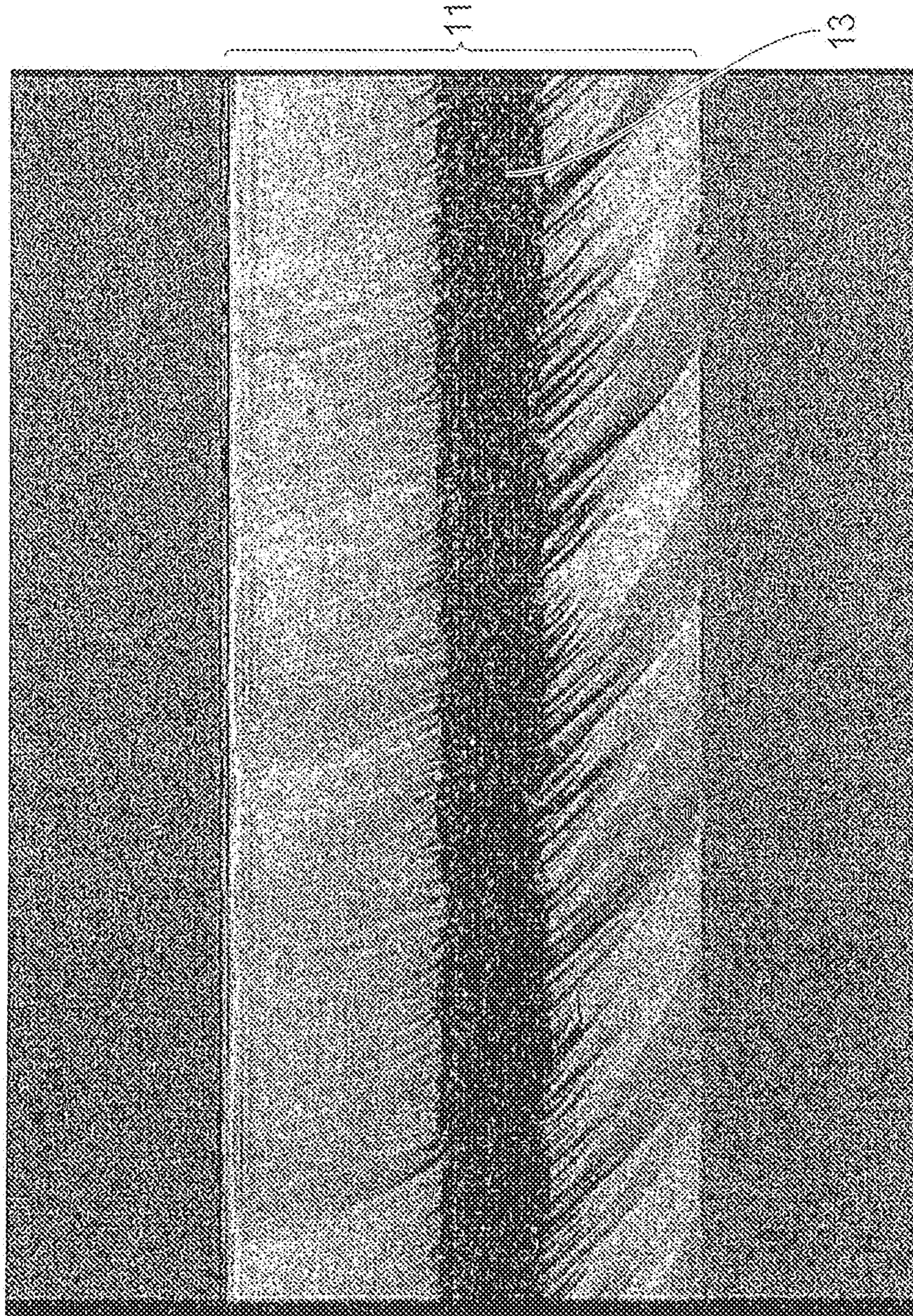
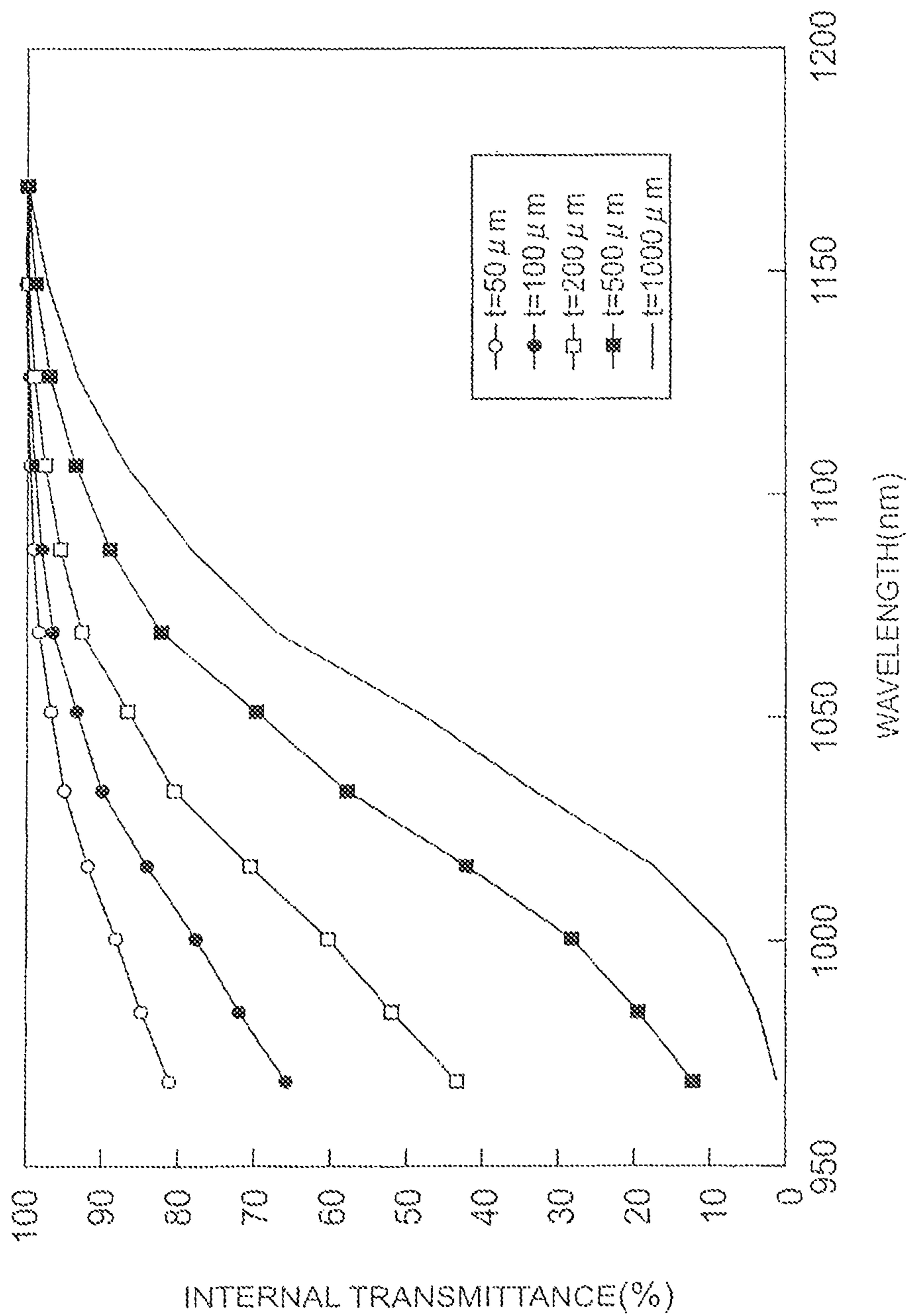


Fig. 12

Fig.13



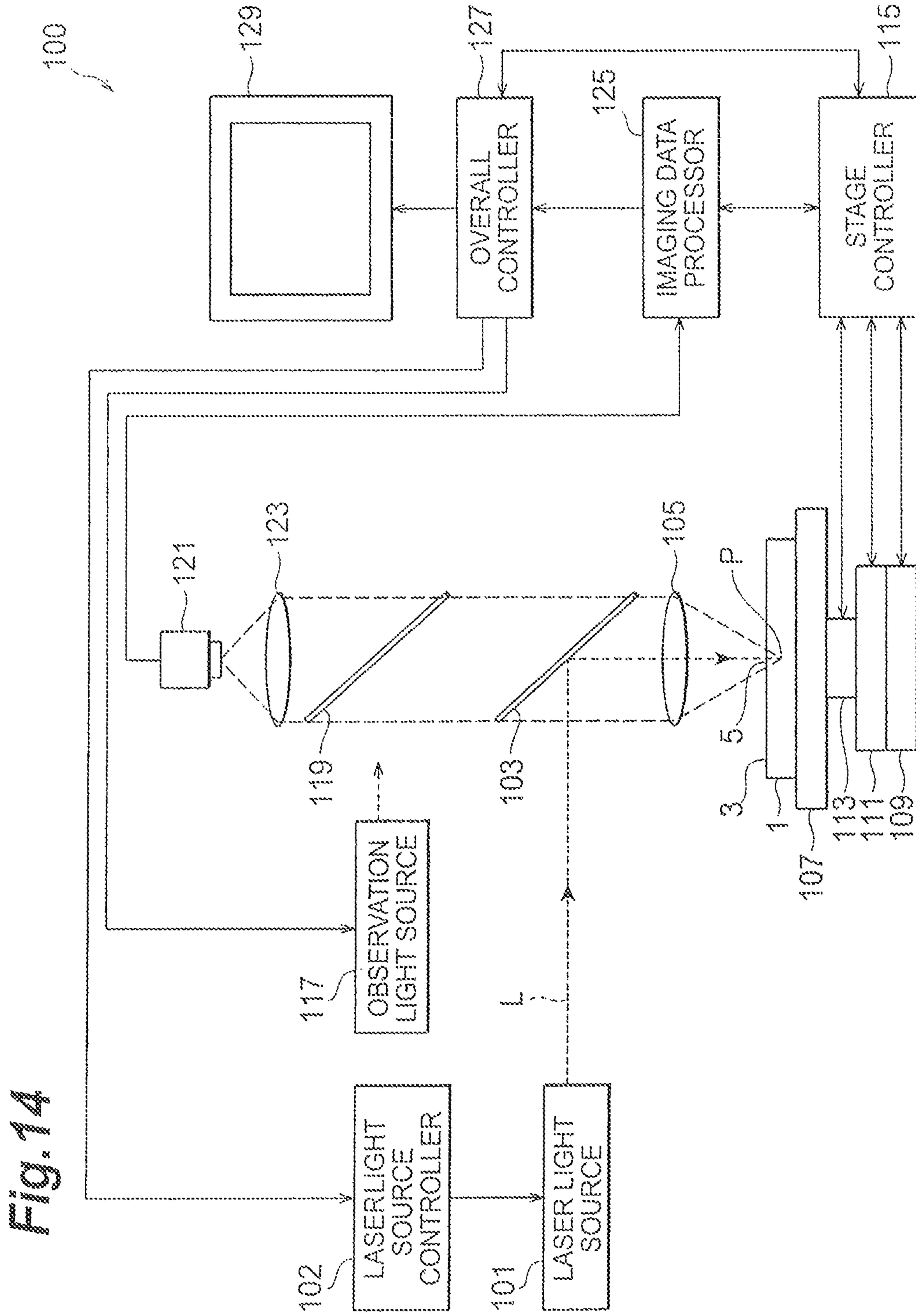


Fig. 15

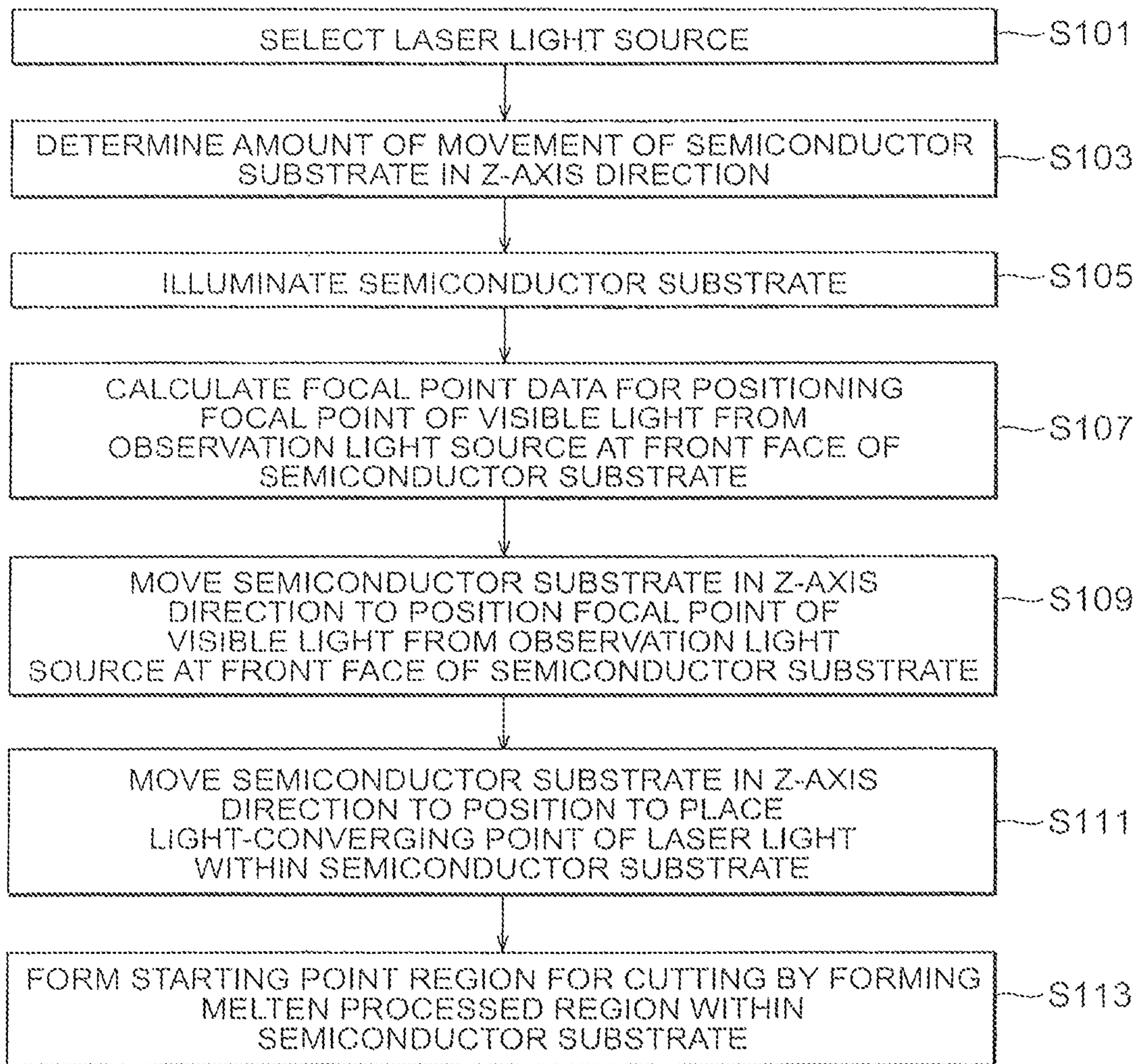


Fig. 16

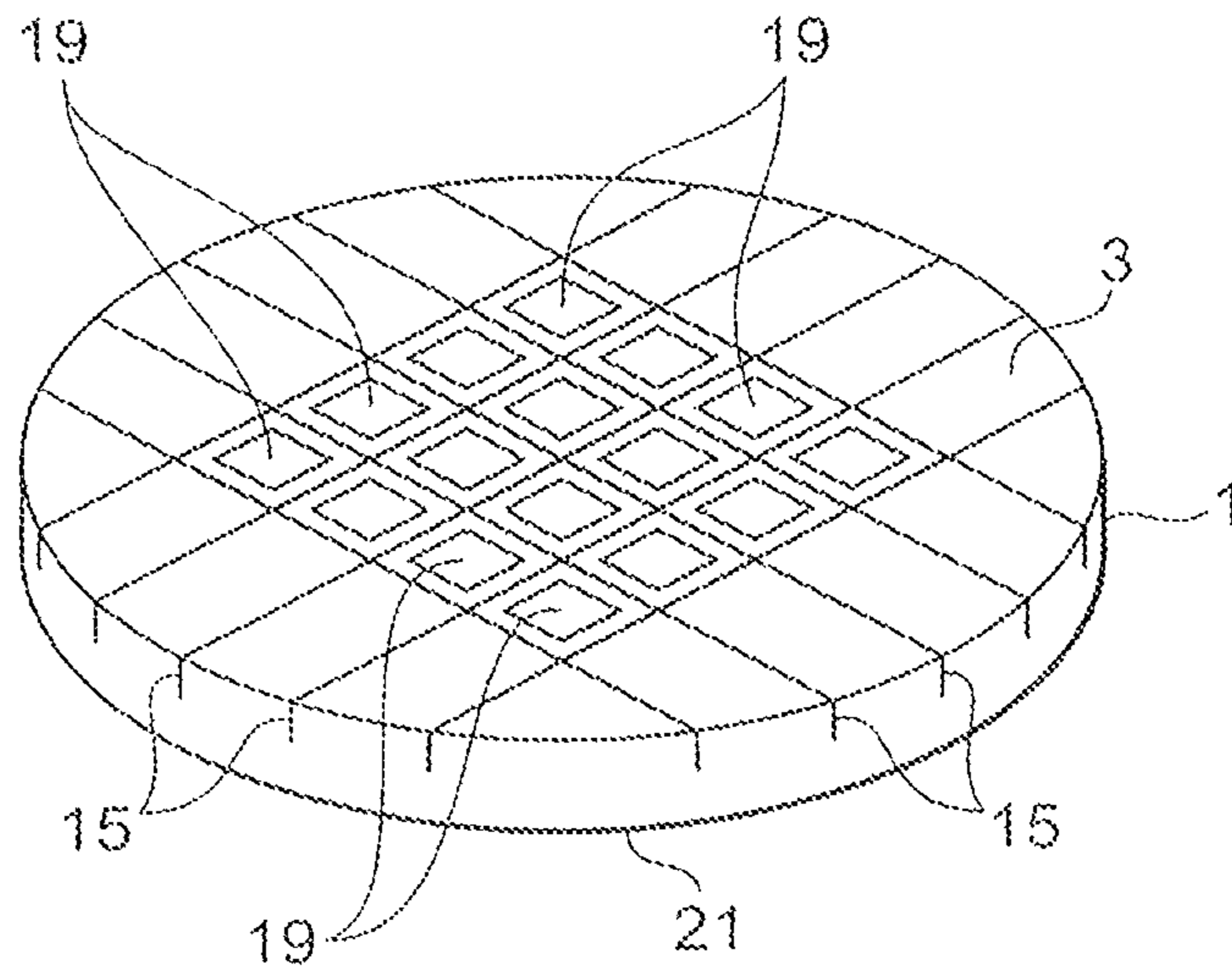


Fig. 17

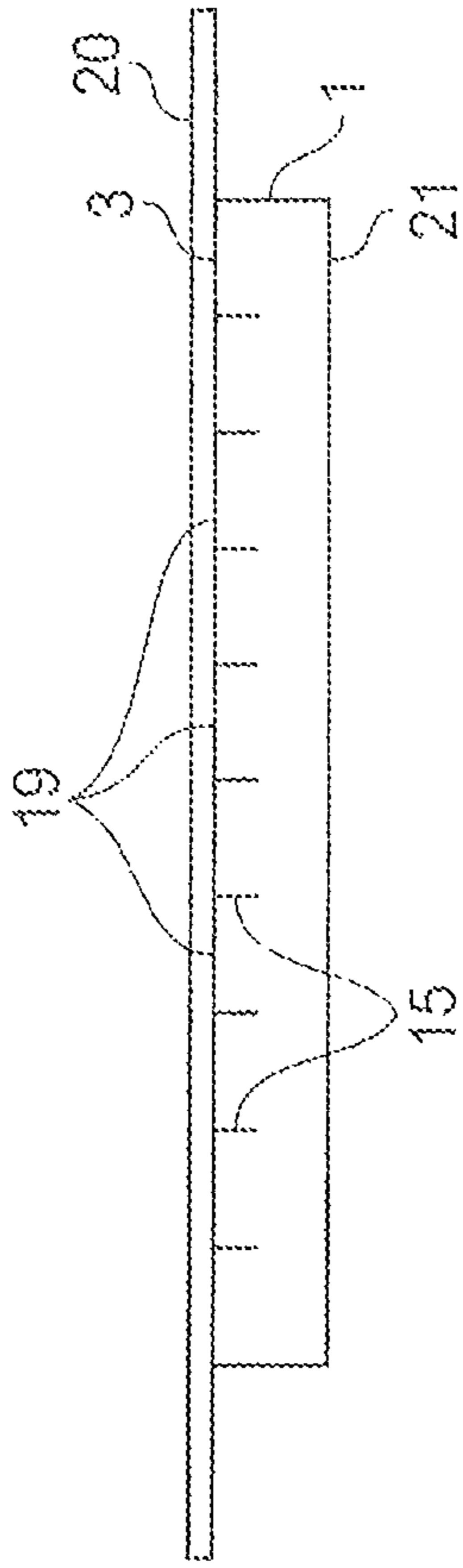


Fig. 18

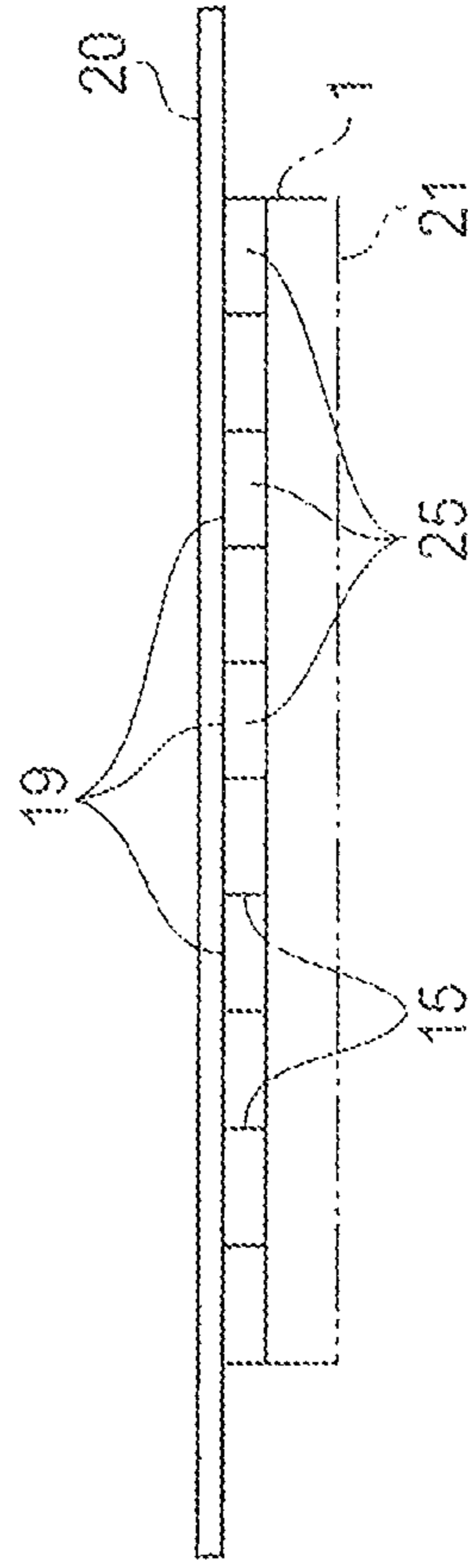


Fig. 19

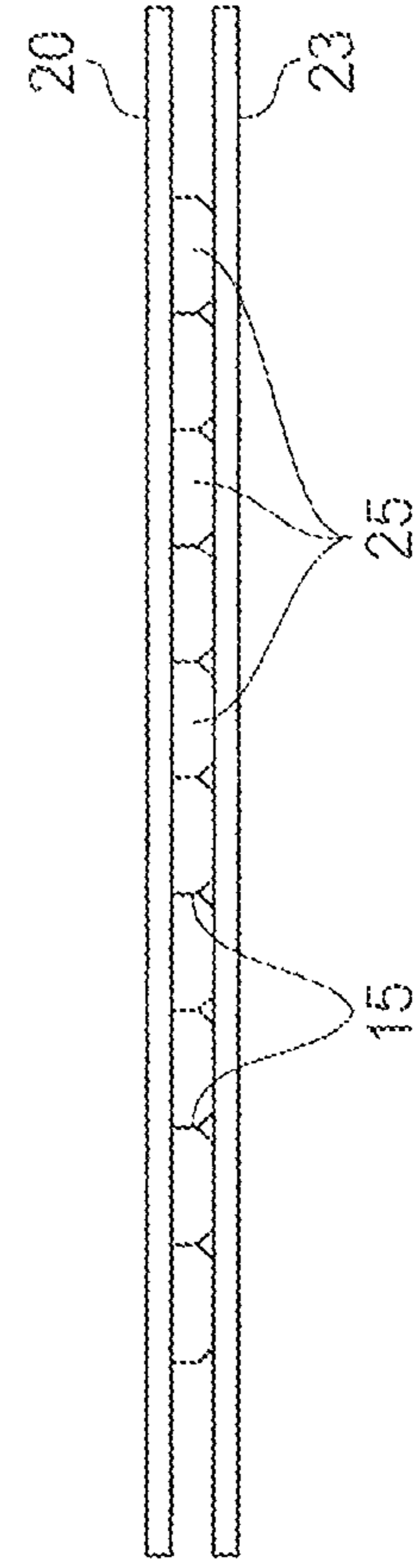


Fig. 20

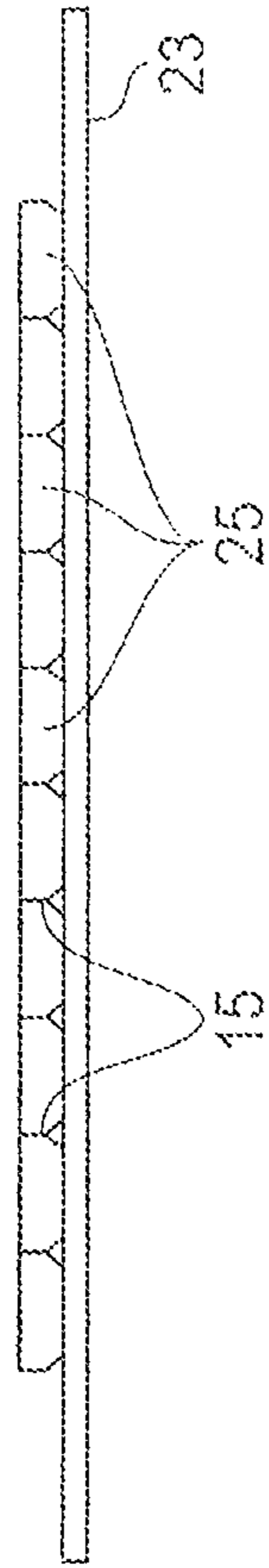


Fig. 21

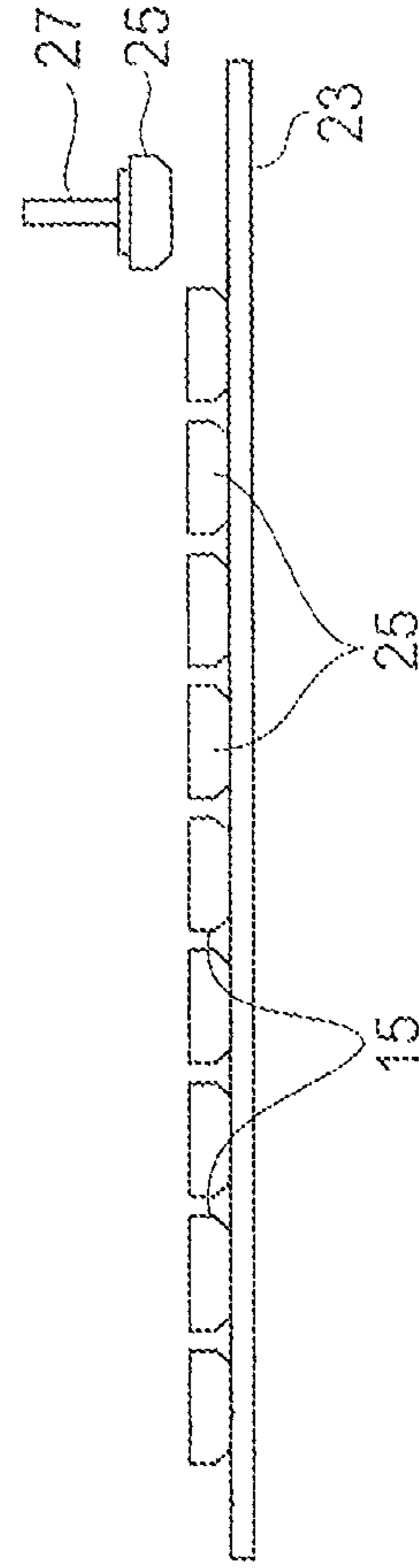


Fig. 22

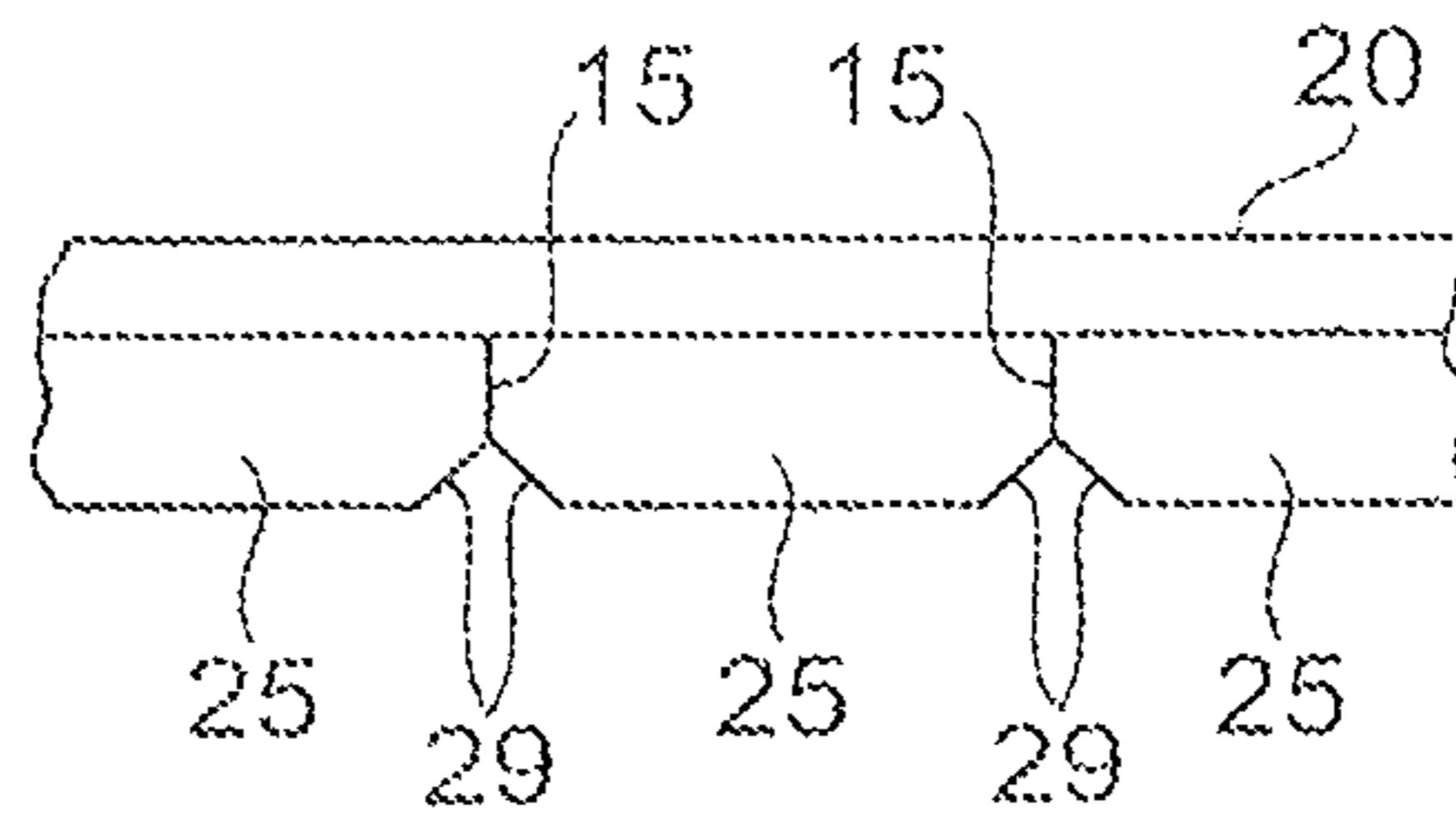


Fig. 23A

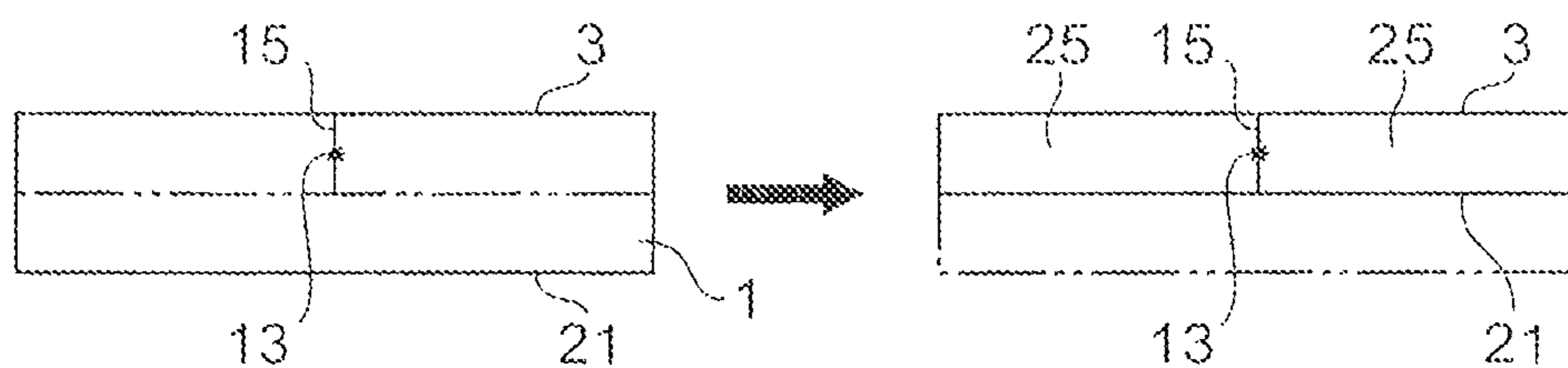


Fig. 23B

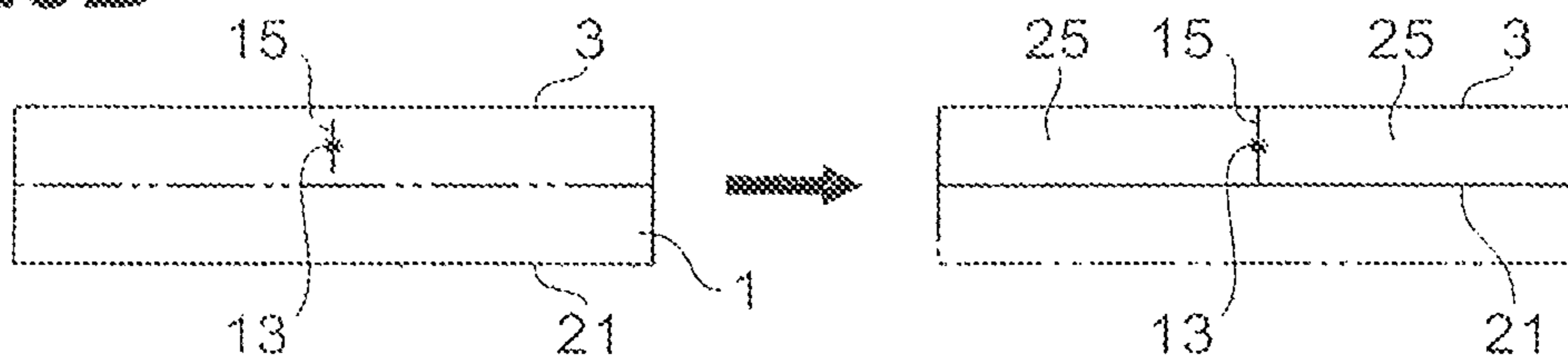


Fig. 24A

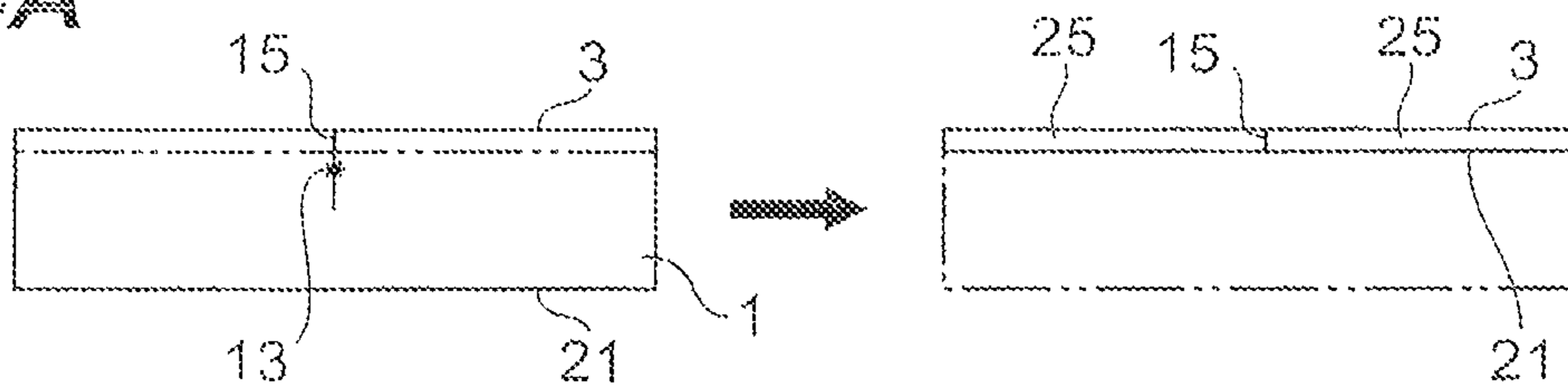


Fig. 24B

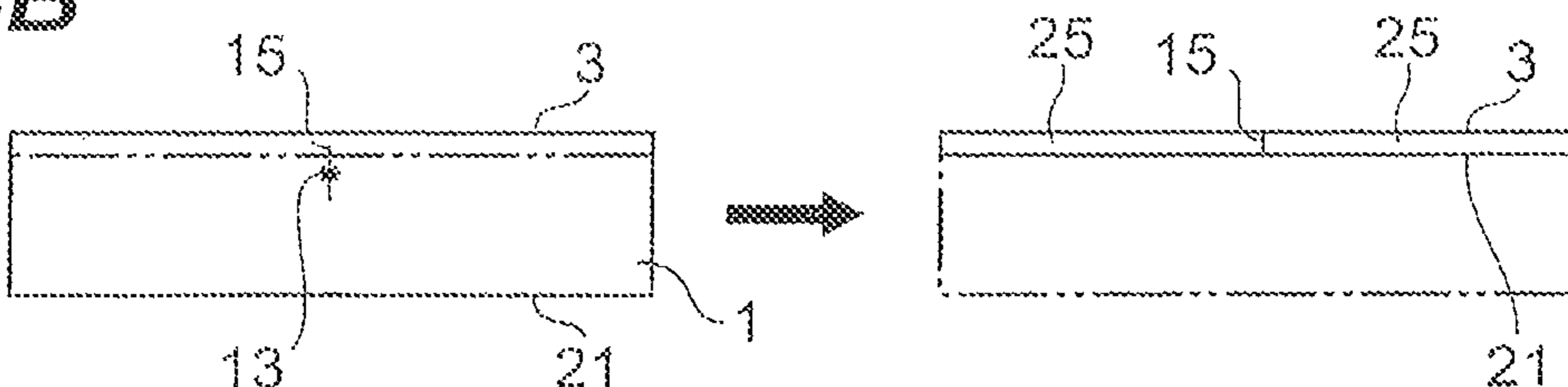


Fig. 25A

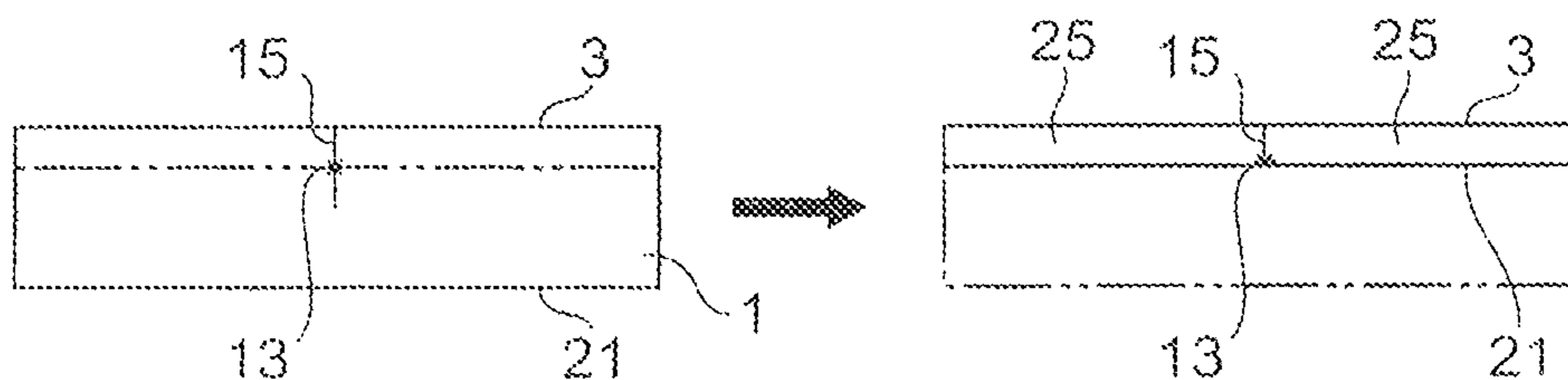


Fig. 25B

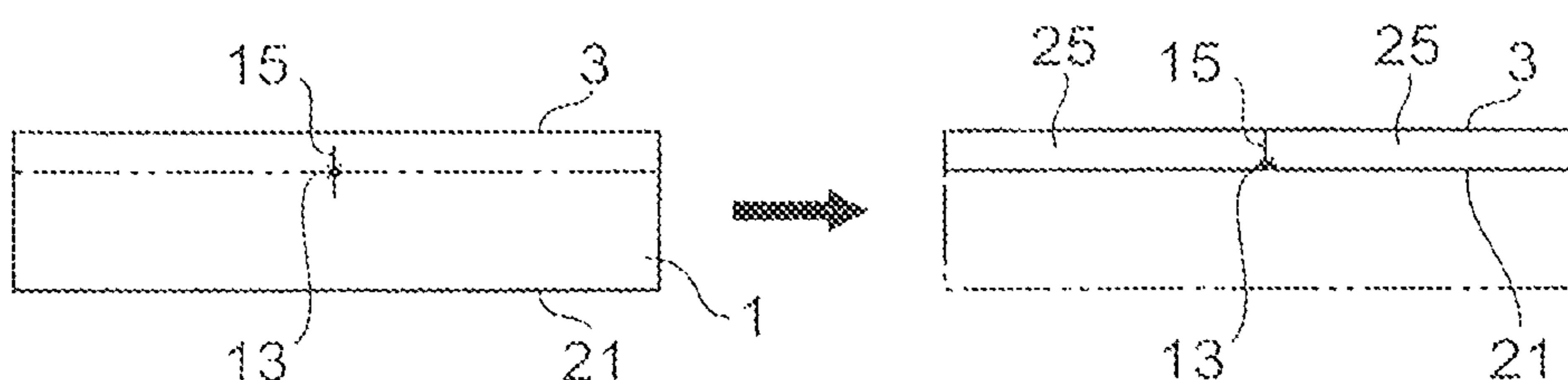


Fig. 26A

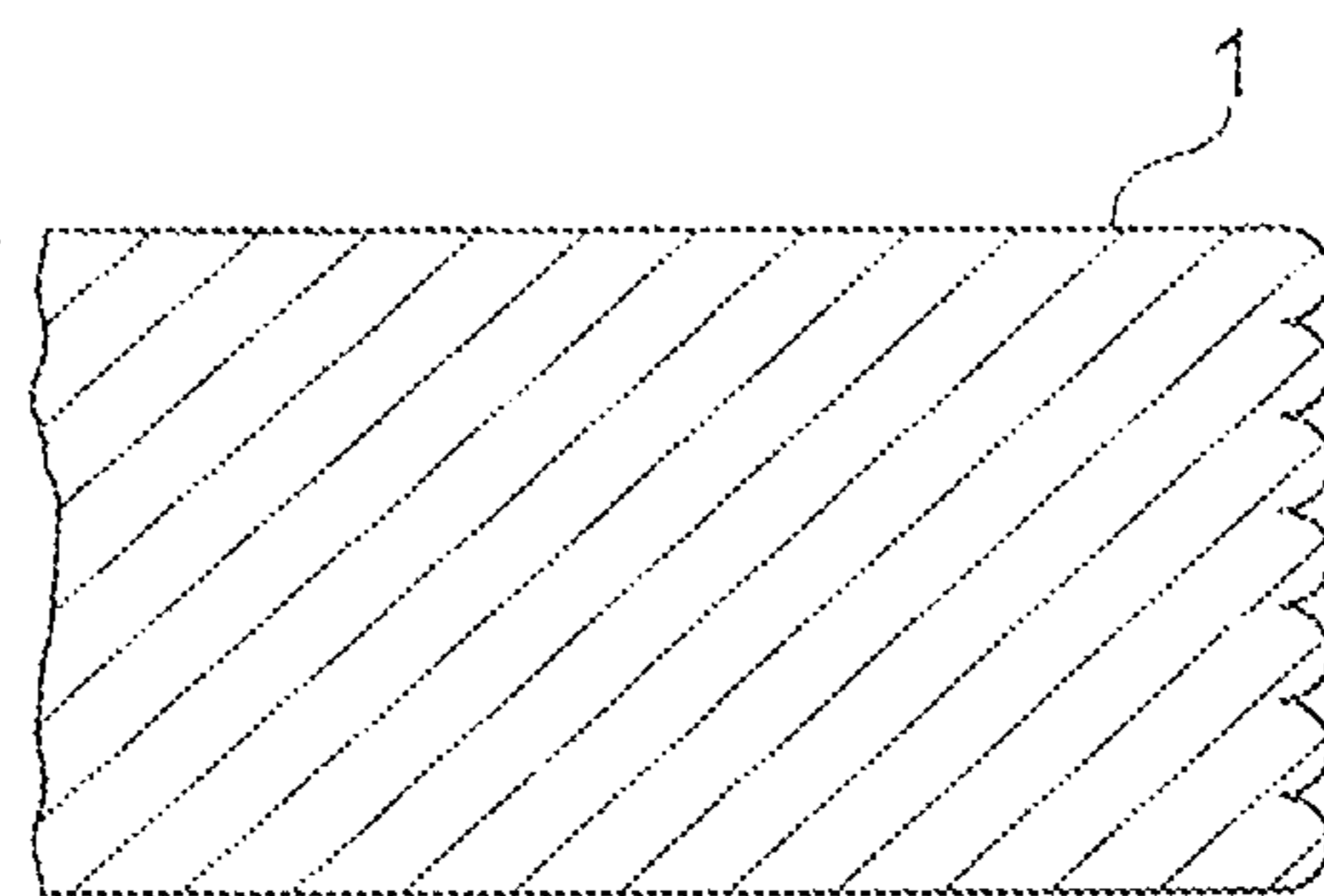


Fig. 26B

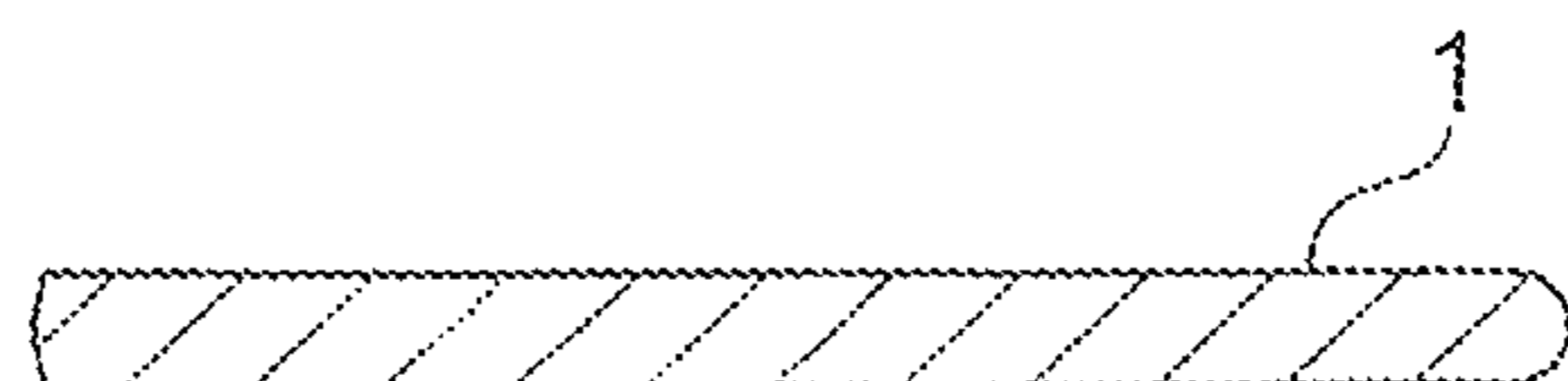


Fig. 27

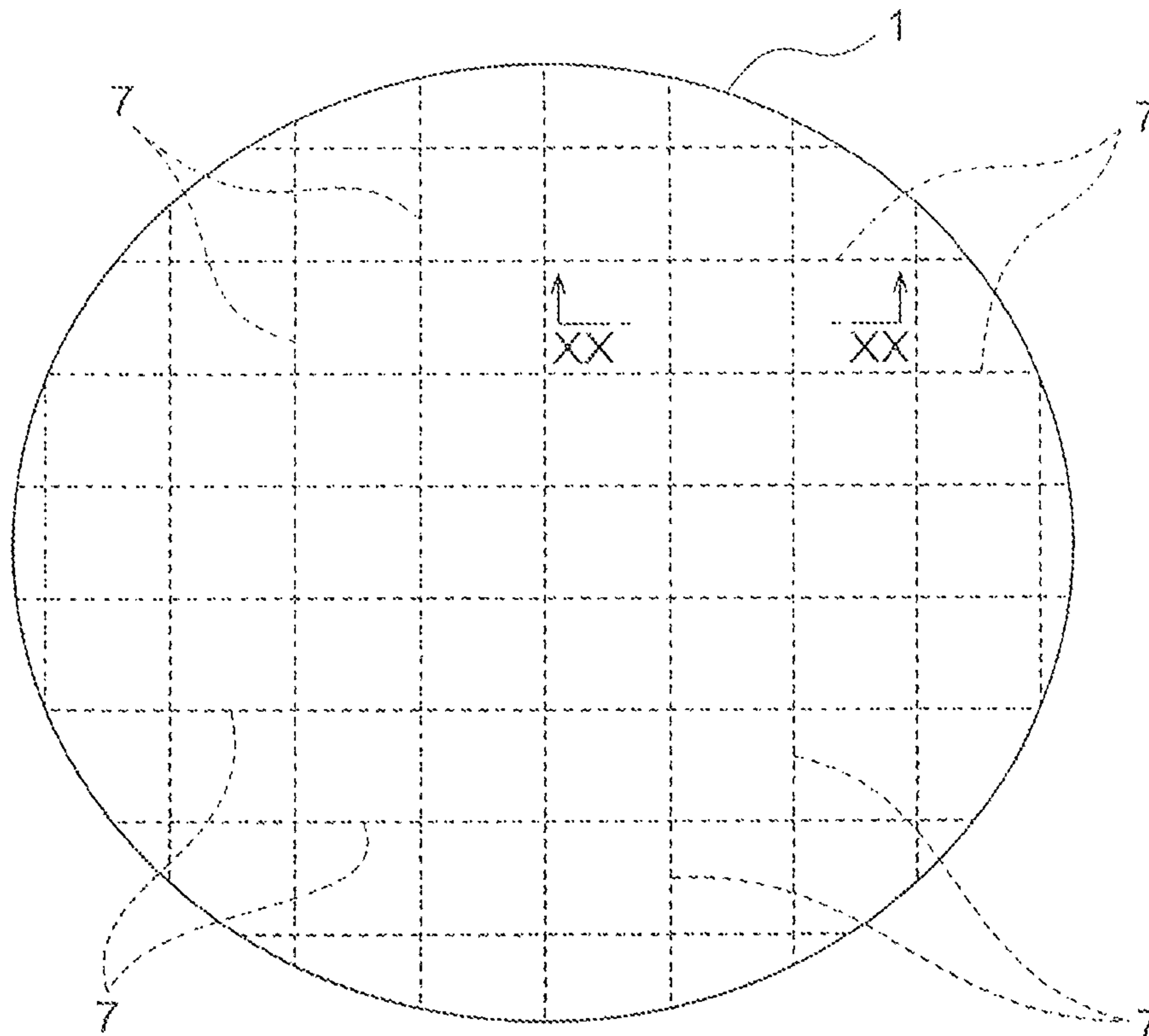


Fig.28

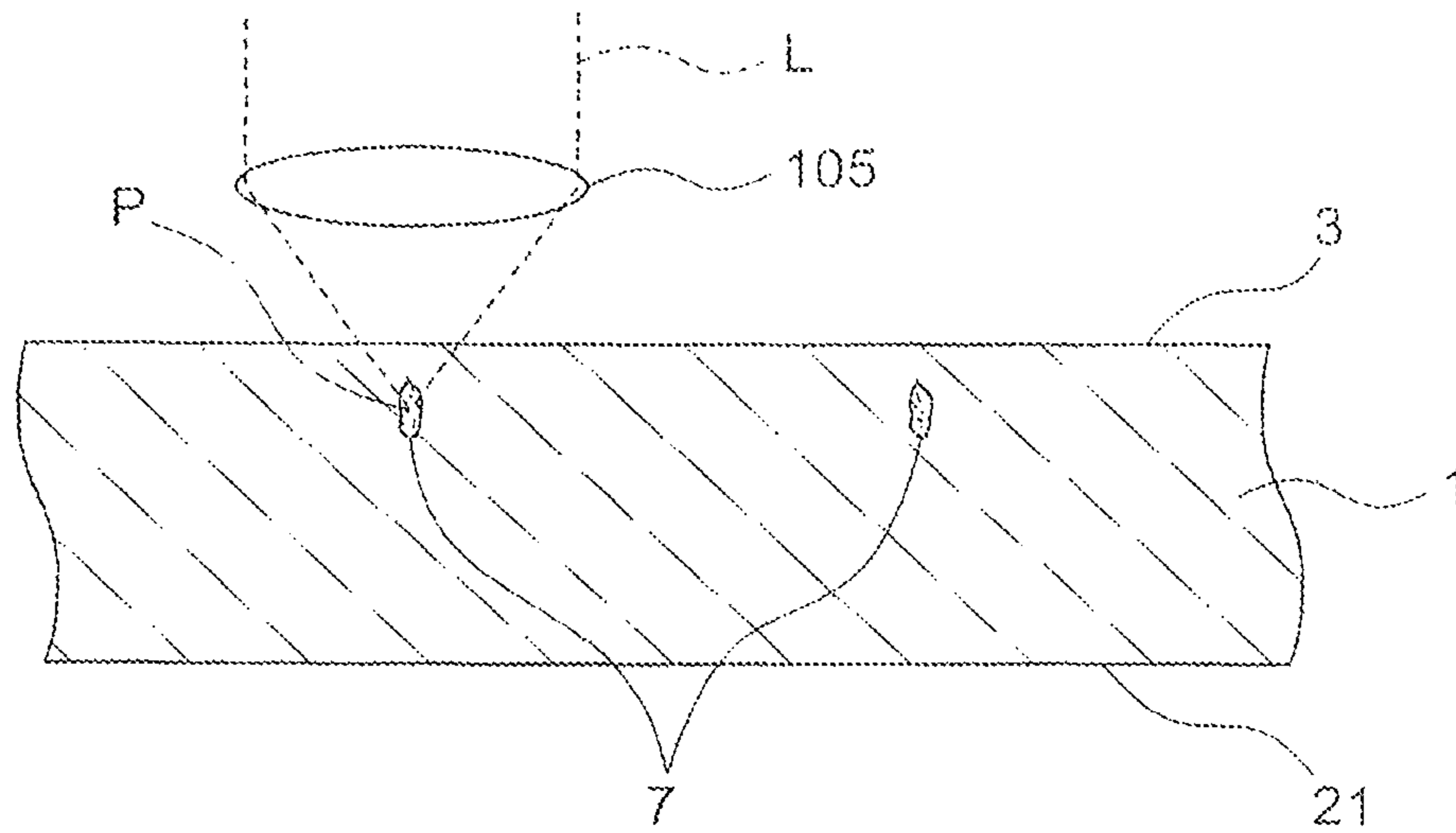


Fig.29

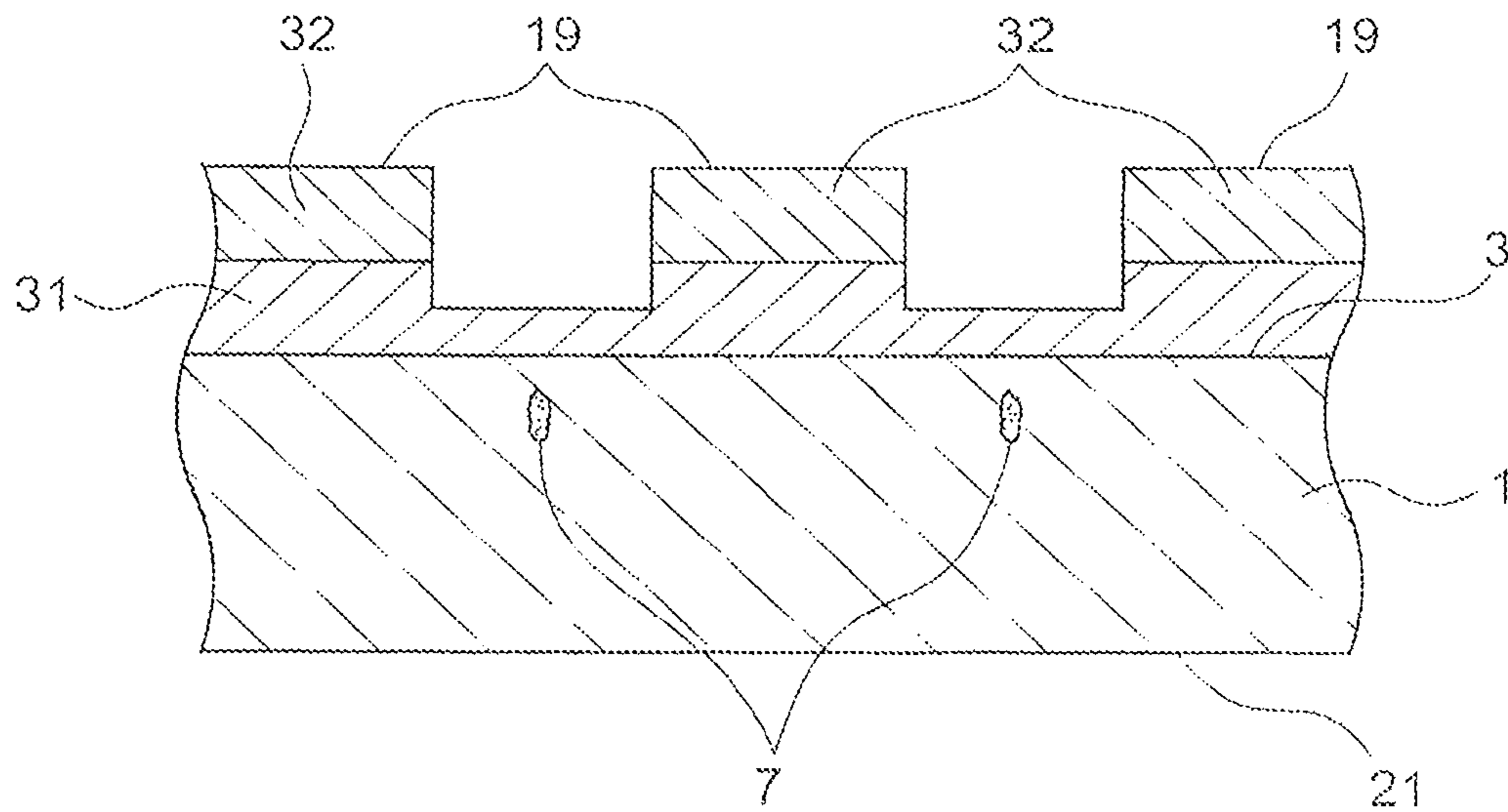


Fig. 30

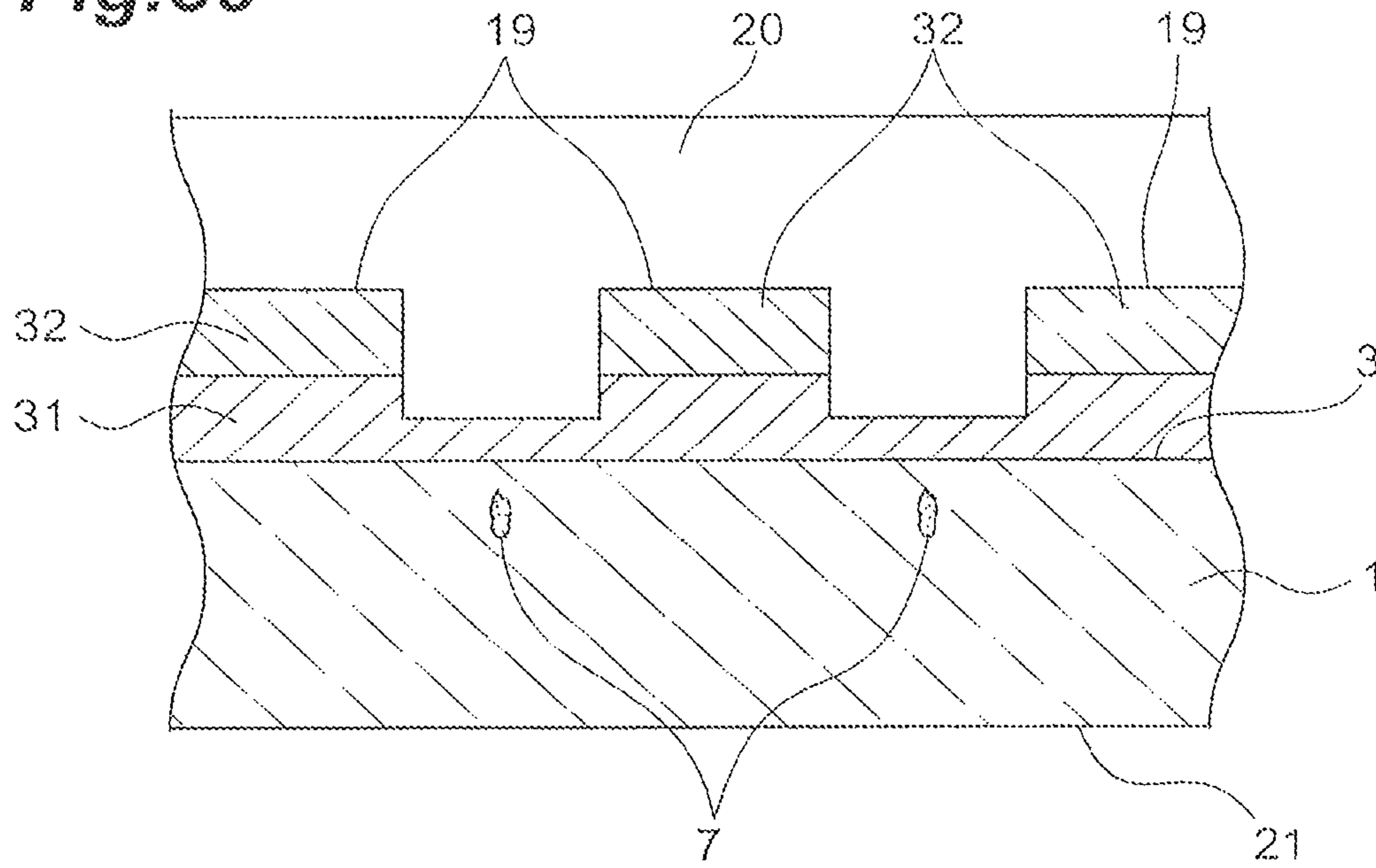


Fig. 31

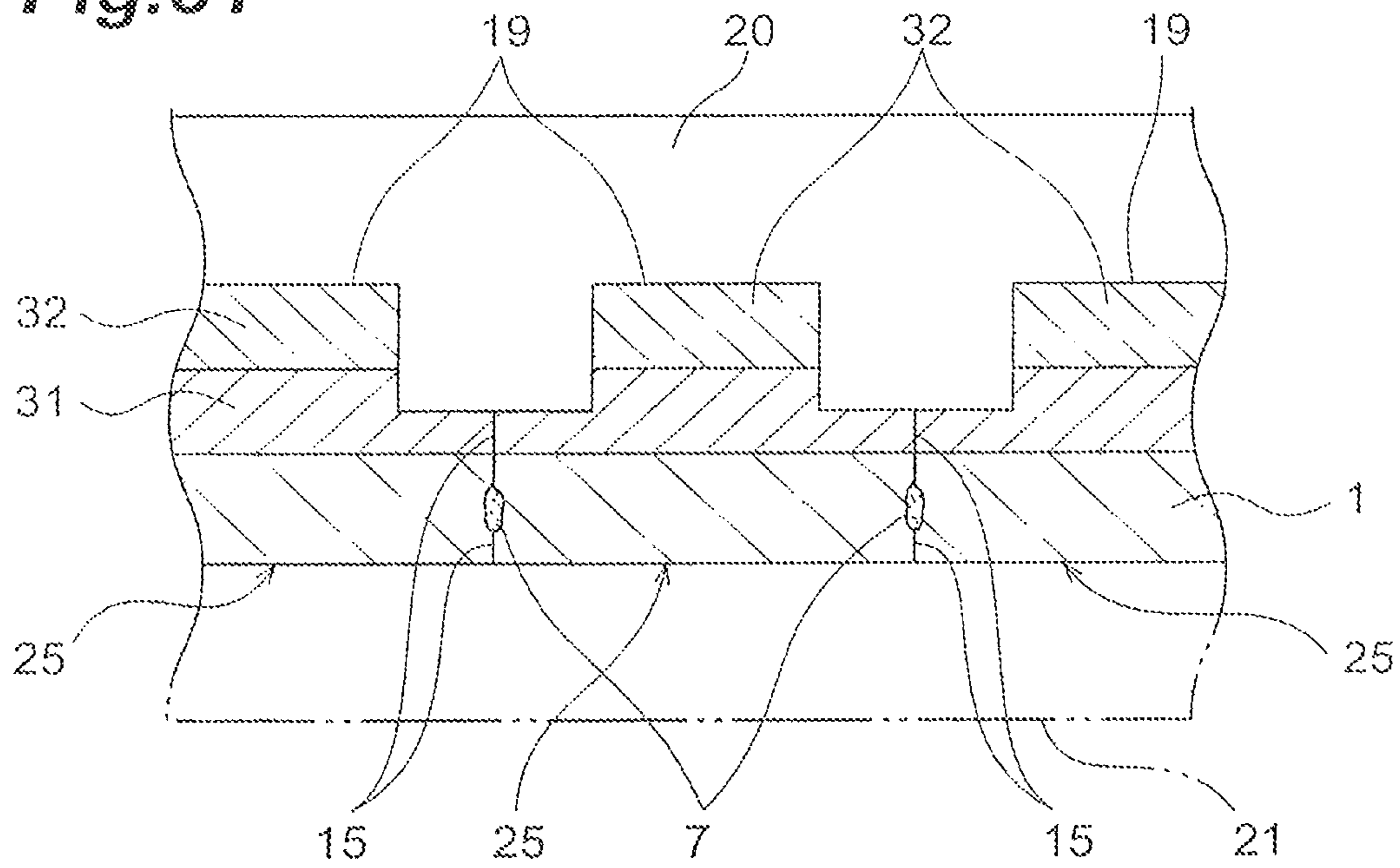


Fig. 32

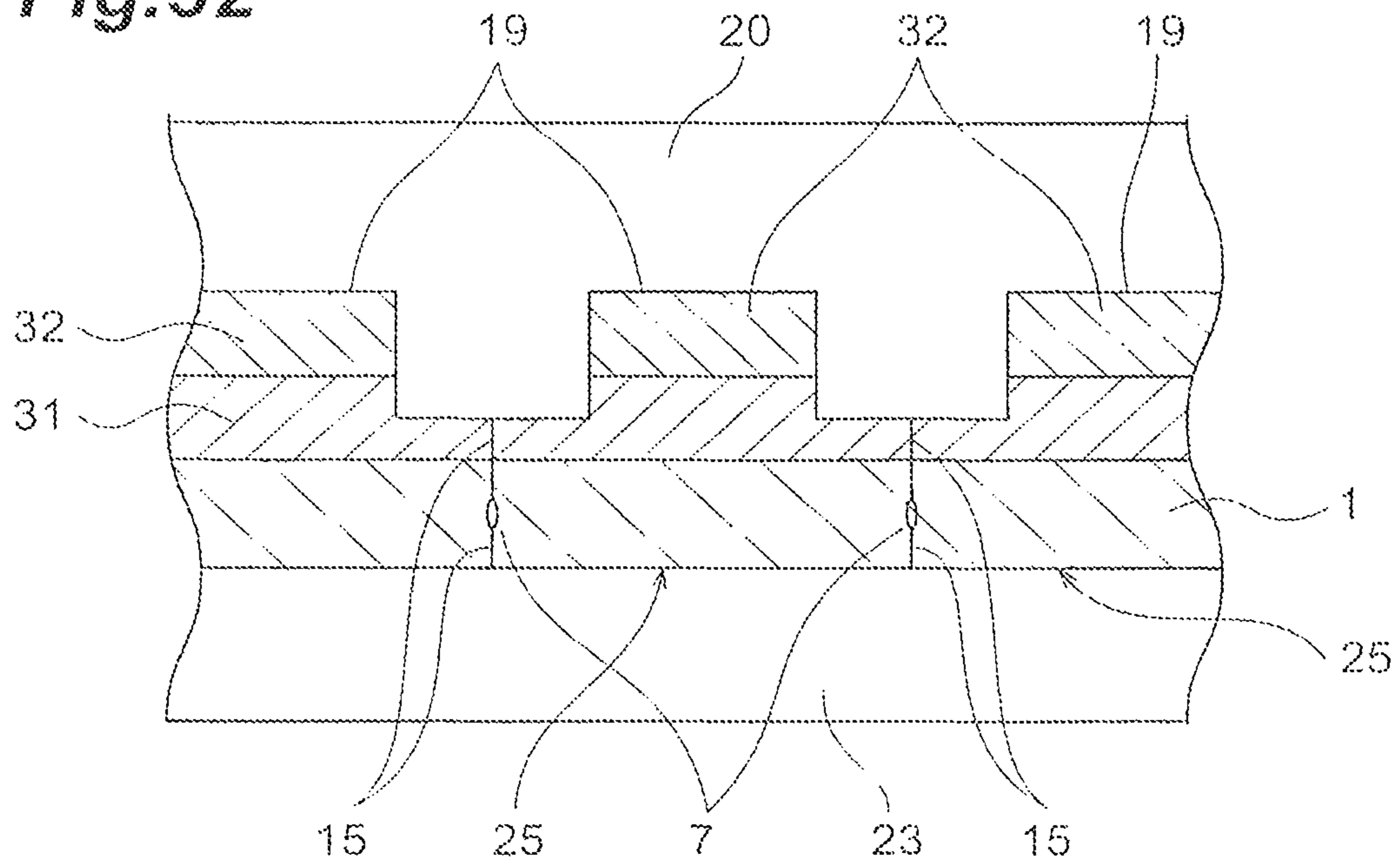


Fig. 33

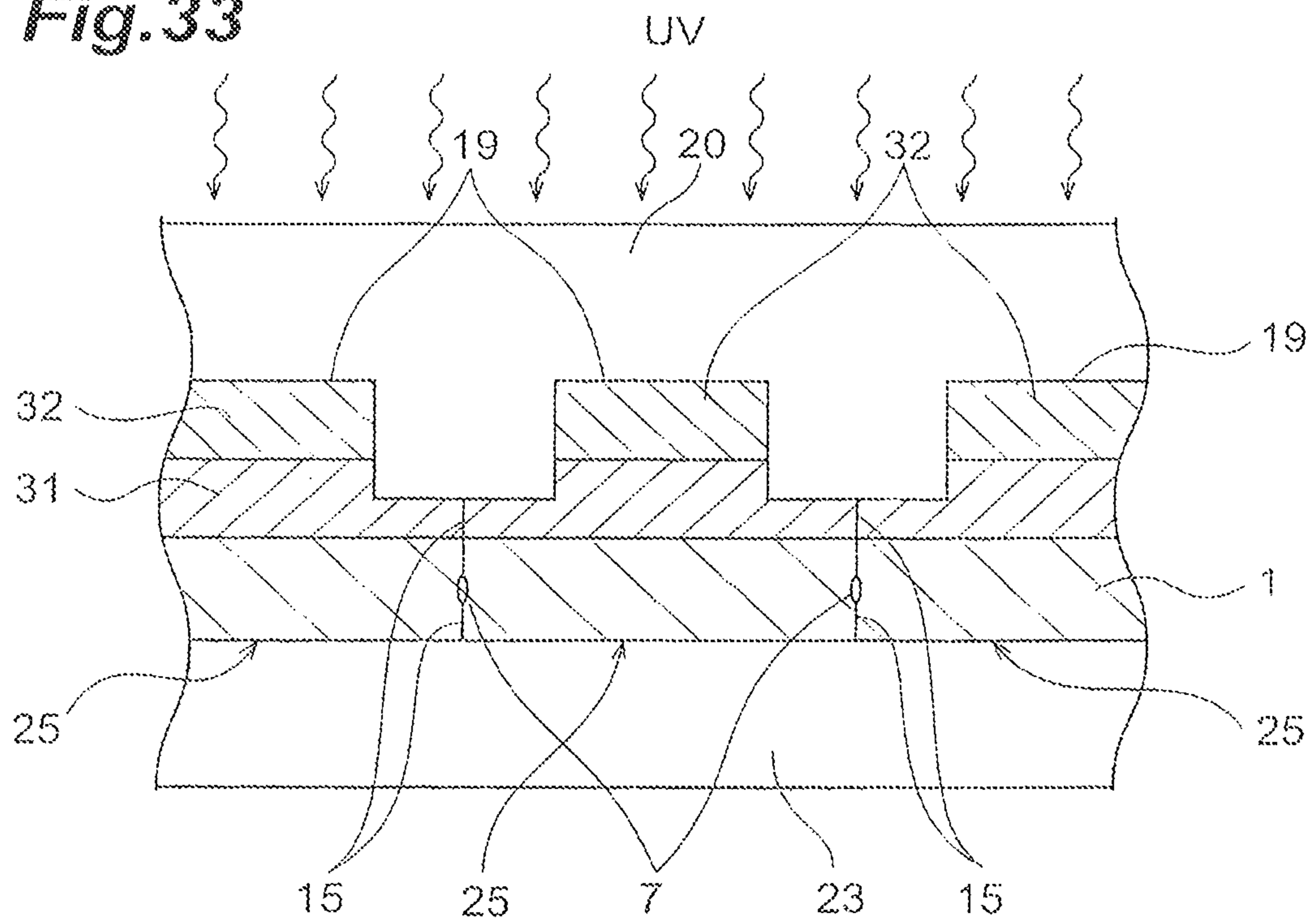


Fig.34

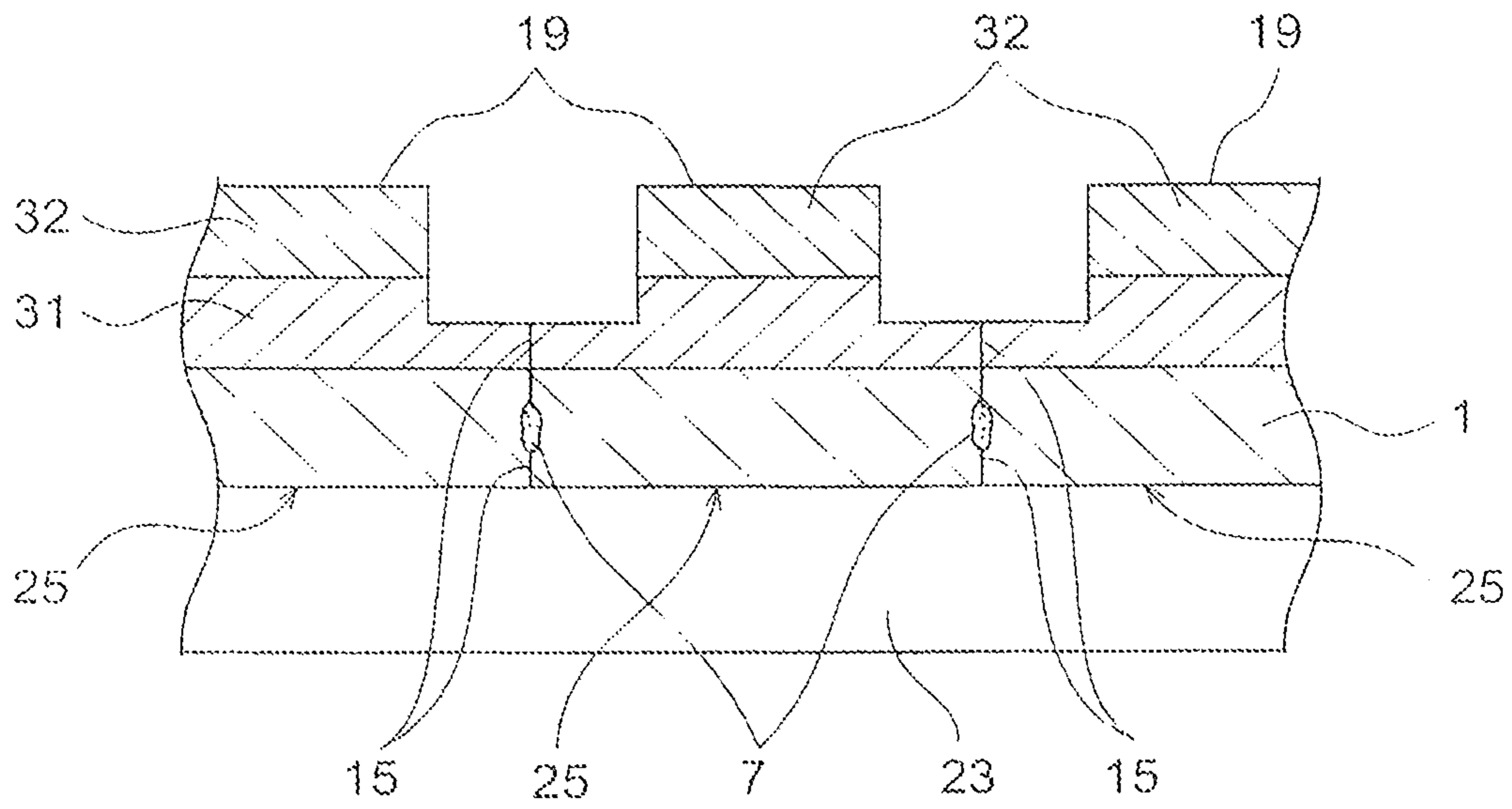
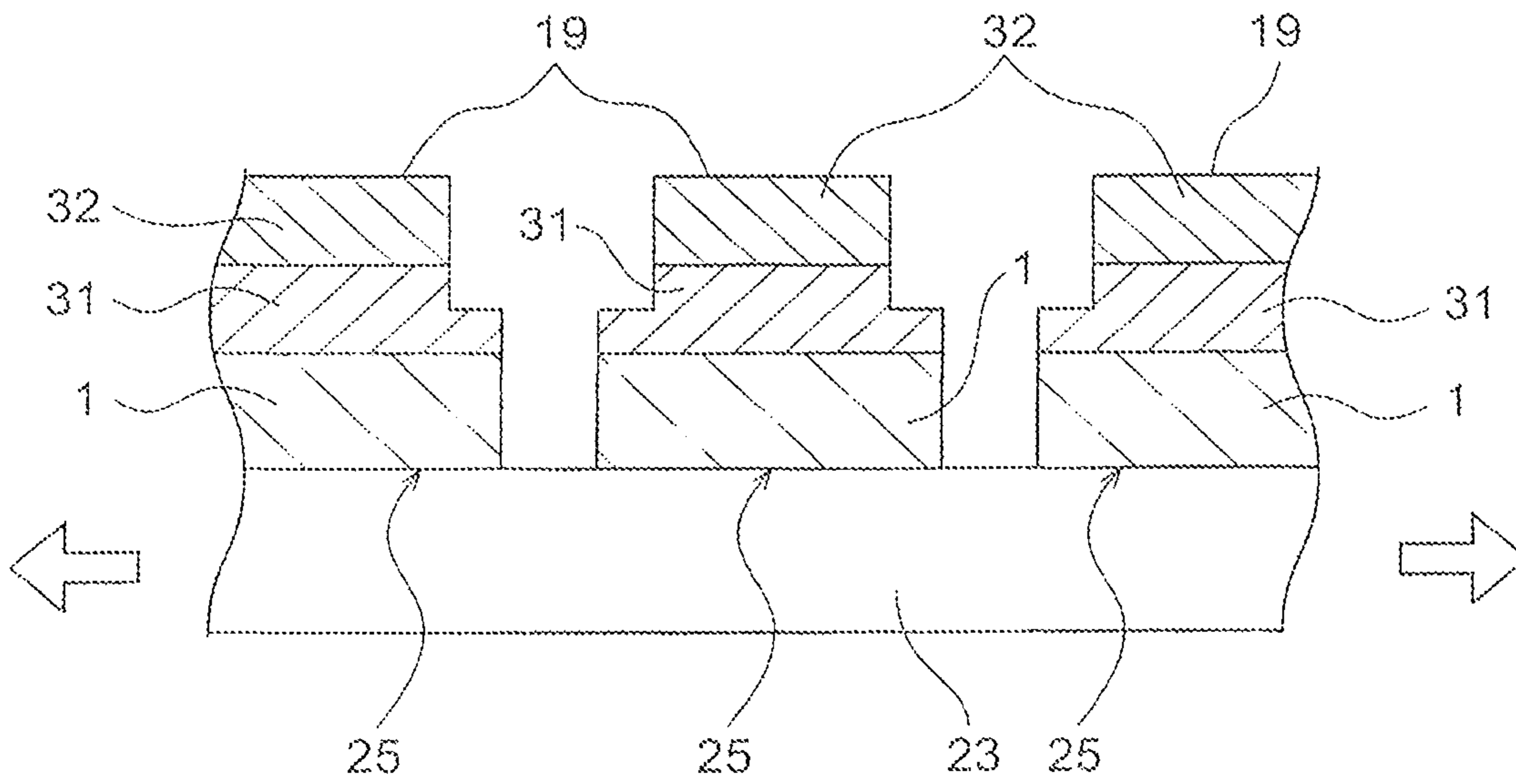


Fig.35



SUBSTRATE DIVIDING METHOD

This is a continuation application of copending application Ser. No. 15/617,431, filed Jun. 8, 2017, which is a continuation of application Ser. No. 14/984,066, filed Dec. 30, 2015, (now U.S. Pat. No. 9,711,405), which is a continuation of application Ser. No. 14/793,181, filed on Jul. 7, 2015 (now U.S. Pat. No. 9,287,177), which is a continuation of application Ser. No. 14/517,552, filed on Oct. 17, 2014 (now U.S. Pat. No. 9,142,458), which is a continuation of application Ser. No. 13/953,443, filed on Jul. 29, 2013 (now U.S. Pat. No. 8,889,525), which is a continuation of application Ser. No. 13/618,699, filed on Sep. 14, 2012 (now U.S. Pat. No. 8,519,511), which is a continuation of application Ser. No. 10/507,321, filed on Jun. 28, 2005 (now U.S. Pat. No. 8,268,704), which is the National Stage of International Application No. PCT/JP03/02669 filed Mar. 6, 2003, the entire contents of each of these being incorporated by reference herein in their entirety.

TECHNICAL FIELD

The present invention relates to a substrate dividing method used for dividing a substrate such as a semiconductor substrate in a step of making a semiconductor device or the like.

BACKGROUND ART

As semiconductor devices have been becoming smaller in recent years, there are cases where a semiconductor substrate is thinned to a thickness of several tens of micrometers in a step of making a semiconductor device. When thus thinned semiconductor substrate is cut and divided by a blade, chipping and cracking occur more than in the case where a semiconductor substrate is thicker, thereby causing a problem that the yield of semiconductor chips obtained by dividing the semiconductor substrate decreases.

Known as semiconductor substrate dividing methods which can solve such a problem are those described in Japanese Patent Application Laid-Open Nos. SHO 64-38209 and SHO 62-4341.

In the methods described in these publications, a semiconductor substrate having a front face formed with a functional device is inscribed with a groove by a blade on the front face side, then an adhesive sheet is attached to the front face, so as to hold the semiconductor substrate, and the rear face of the semiconductor substrate is ground until the groove formed beforehand is exposed, thereby thinning the semiconductor substrate and dividing the semiconductor substrate.

DISCLOSURE OF THE INVENTION

If the grinding of the rear face of the semiconductor substrate is performed by surface grinding in the methods described in the above-mentioned publications, however, chipping and cracking may occur at side faces of the groove formed beforehand in the semiconductor substrate when the surface-ground face reaches the groove.

In view of such a circumstance, it is an object of the present invention to provide a substrate dividing method which can prevent chipping and cracking from occurring, and thin and divide a substrate.

For achieving the above-mentioned object, the substrate dividing method in accordance with the present invention comprises the steps of irradiating a substrate with laser light

while positioning a light-converging point within the substrate, so as to form a modified region due- to multiphoton absorption within the substrate, and causing the modified region to form a starting point region for cutting along a line along which the substrate should be cut in the substrate inside by a predetermined distance from a laser light incident face of the substrate; and grinding the substrate after the step of forming the starting point region for cutting such that the substrate attains a predetermined thickness.

Since this substrate dividing method irradiates the substrate with laser light while positioning a light-converging point within the substrate in the step of forming a starting point region for cutting, so as to generate a phenomenon of multiphoton absorption within the substrate, thereby forming a modified region, this modified region can form a starting point region for cutting within the substrate along a desirable line along which the substrate should be cut for cutting the substrate. When a starting point region for cutting is formed within the substrate, a fracture is generated in the substrate in its thickness direction from the starting point region for cutting acting as a start point naturally or with a relatively small force exerted thereon.

In the step of grinding the substrate, the substrate is ground such that the substrate attains a predetermined thickness after the starting point region for cutting is formed within the substrate. Here, even when the ground surface reaches the fracture generated from the starting point region for cutting acting as a start point, cut surfaces of the substrate cut by the fracture remain in close contact with each other, whereby the substrate can be prevented from chipping and cracking upon grinding.

This can prevent chipping and cracking from occurring, and can thin and divide the substrate.

Here, the light-converging point refers to a location at which laser light is converged. The grinding encompasses shaving, polishing, chemical etching, and the like. The starting point region for cutting refers to a region to become a start point for cutting when the substrate is cut. Therefore, the starting point region for cutting is a part to cut where cutting is to be performed in the substrate. The starting point region for cutting may be produced by continuously forming a modified region or intermittently forming a modified region.

The substrate encompasses semiconductor substrates such as silicon substrates and GaAs substrates, and insulating substrates such as sapphire substrates and AlN substrates. When the substrate is a semiconductor substrate, an example of the modified region is a molten processed region.

Preferably, a front face of the substrate is formed with a functional device, and a rear face of the substrate is ground in the step of grinding the substrate. Since the substrate can be ground after forming the functional device, a chip thinned so as to conform to a smaller size of a semiconductor device, for example, can be obtained. Here, the functional device refers to light-receiving devices such as photodiodes, light-emitting devices such as laser diodes, circuit devices formed as circuits, etc.

Preferably, the step of grinding the substrate includes a step of subjecting the rear face of the substrate to chemical etching. When the rear face of the substrate is subjected to chemical etching, the rear face of the substrate becomes smoother as a matter of course. Also, since the cut surfaces of the substrate cut by the fracture generated from the starting point region for cutting acting as a start point remain in close contact with each other, only edge parts on the rear face of the cut surfaces are selectively etched, so as to be chamfered. This can improve the transverse rupture strength

of chips obtained by dividing the substrate, and prevent chipping and cracking from occurring in the chips.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of an object to be processed during laser processing in the laser processing method in accordance with an embodiment of the present invention;

FIG. 2 is a sectional view of the object to be processed taken along the line II-II of FIG. 1;

FIG. 3 is a plan view of the object to be processed after laser processing by the laser processing method in accordance with the embodiment;

FIG. 4 is a sectional view of the object to be processed taken along the line IV-IV of FIG. 3;

FIG. 5 is a sectional view of the object to be processed taken along the line V-V of FIG. 3;

FIG. 6 is a plan view of the object to be processed cut by the laser processing method in accordance with the embodiment;

FIG. 7 is a graph showing relationships between the electric field intensity and crack spot size in the laser processing method in accordance with the embodiment;

FIG. 8 is a sectional view of the object to be processed in a first step of the laser processing method in accordance with the embodiment;

FIG. 9 is a sectional view of the object to be processed in a second step of the laser processing method in accordance with the embodiment;

FIG. 10 is a sectional view of the object to be processed in a third step of the laser processing method in accordance with the embodiment;

FIG. 11 is a sectional view of the object to be processed in a fourth step of the laser processing method in accordance with the embodiment;

FIG. 12 is a view showing a photograph of a cut section in a part of a silicon wafer cut by the laser processing method in accordance with the embodiment;

FIG. 13 is a graph showing relationships between the laser light wavelength and the internal transmittance of a silicon substrate in the laser processing method in accordance with the embodiment;

FIG. 14 is a schematic diagram of the laser processing apparatus in accordance with Example 1;

FIG. 15 is a flowchart for explaining the laser processing method in accordance with Example 1;

FIG. 16 is a view showing the semiconductor substrate after a step of forming a starting point region for cutting in accordance with Example 1;

FIG. 17 is a view for explaining a step of attaching a protective film in accordance with Example 1;

FIG. 18 is a view for explaining a step of grinding the semiconductor substrate in accordance with Example 1;

FIG. 19 is a view for explaining a step of attaching an expansion film in accordance with Example 1;

FIG. 20 is a view for explaining a step of peeling the protective film in accordance with Example 1;

FIG. 21 is a view for explaining a step of expanding the expansion film and picking up semiconductor chips in accordance with Example 1;

FIG. 22 is a view showing chamfers formed at edge parts on the rear face side of cut surfaces of semiconductor chips after the step of grinding the semiconductor substrate in accordance with Example 1;

FIG. 23A is a view for explaining a case where a molten processed region remains in a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in

accordance with Example 1, while a fracture reaches the front face before the step of grinding the semiconductor substrate;

FIG. 23B is a view for explaining a case where a molten processed region remains in a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in accordance with Example 1, while a fracture does not reach the front face before the step of grinding the semiconductor substrate;

FIG. 24A is a view for explaining a case where a molten processed region does not remain in a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in accordance with Example 1, while a fracture reaches the front face before the step of grinding the semiconductor substrate;

FIG. 24B is a view for explaining a case where a molten processed region does not remain in a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in accordance with Example 1, while a fracture does not reach the front face before the step of grinding the semiconductor substrate;

FIG. 25A is a view for explaining a case where a molten processed region remains in an edge part on the rear face side of a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in accordance with Example 1, while a fracture reaches the front face before the step of grinding the semiconductor substrate;

FIG. 25B is a view for explaining a case where a molten processed region remains in an edge part on the rear face side of a cut surface of a semiconductor chip after the step of grinding the semiconductor substrate in accordance with Example 1, while a fracture does not reach the front face before the step of grinding the semiconductor substrate;

FIG. 26A is a sectional view of a marginal part of the semiconductor substrate before the step of grinding the semiconductor substrate in accordance with Example 1;

FIG. 26B is a sectional view of the marginal part of the semiconductor substrate after the step of grinding the semiconductor substrate in accordance with Example 1;

FIG. 27 is a plan view of the sapphire substrate in accordance with Example 2;

FIG. 28 is a sectional view for explaining a step of forming a starting point region for cutting in accordance with Example 2;

FIG. 29 is a sectional view for explaining a step of forming a functional device in accordance with Example 2;

FIG. 30 is a sectional view for explaining a step of attaching a protective film in accordance with Example 2;

FIG. 31 is a sectional view for explaining a step of grinding the sapphire substrate in accordance with Example 2;

FIG. 32 is a sectional view for explaining a step of attaching an expansion film in accordance with Example 2;

FIG. 33 is a sectional view for explaining a step of irradiating the protective film with UV rays in accordance with Example 2;

FIG. 34 is a sectional view for explaining a step of peeling the protective film in accordance with Example 2; and

FIG. 35 is a sectional view for explaining a step of expanding the expansion film and separating semiconductor chips in accordance with Example 2.

BEST MODES FOR CARRYING OUT THE INVENTION

In the following, a preferred embodiment of the present invention will be explained in detail with reference to

drawings. The substrate dividing method in accordance with this method comprises the steps of irradiating a substrate with laser light while positioning a light-converging point within the substrate, so as to form a modified region due to multiphoton absorption within the substrate, thereby forming a starting point region for cutting; and then grinding the substrate such that the substrate attains a predetermined thickness.

First, a laser processing method carried out in the step of forming the starting point region for cutting, multiphoton absorption in particular, will be explained.

A material becomes optically transparent if its absorption bandgap E_G is greater than a photon energy $h\nu$. Hence, the condition under which absorption occurs in the material is $h\nu > E_G$. However, even when optically transparent, the material yields absorption under the condition of $n h\nu > E_G$ ($n=2, 3, 4, \dots$) if the intensity of laser light is very high. This phenomenon is known as multiphoton absorption. In the case of pulse waves, the intensity of laser light is determined by the peak power density (W/cm^2) of laser light at a light-converging point thereof. The multiphoton absorption occurs, for example, at a peak power density (W/cm^2) of 1×10^8 (W/cm^2) or higher. The peak power density is determined by (energy per pulse of laser light at the light-converging point)/(laser light beam spot cross-sectional area \times pulse width). In the case of a continuous wave, the intensity of laser light is determined by the electric field strength (W/cm^2) of laser light at the light-converging point.

The principle of laser processing in accordance with the embodiment utilizing such multiphoton absorption will now be explained with reference to FIGS. 1 to 6. FIG. 1 is a plan view of a substrate 1 during laser processing; FIG. 2 is a sectional view of the substrate 1 taken along the line II-II of FIG. 1; FIG. 3 is a plan view of the substrate 1 after laser processing; FIG. 4 is a sectional view of the substrate 1 taken along the line IV-IV of FIG. 3; FIG. 5 is a sectional view of the substrate 1 taken along the line V-V of FIG. 3; and FIG. 6 is a plan view of the cut substrate 1.

As shown in FIGS. 1 and 2, the front face 3 of the substrate 1 has a desirable line along which the substrate should be cut 5 for cutting the substrate 1. The line along which the substrate should be cut 5 is a linearly extending virtual line (the substrate 1 may also be formed with an actual line acting as the line along which the substrate should be cut 5). In the laser processing in accordance with this embodiment, the substrate 1 is irradiated with laser light L such that a light-converging point P is positioned within the semiconductor substrate 1 under a condition causing multiphoton absorption, so as to form a modified region 7. Here, the light, converging point is a location where the laser light L is converged.

The laser light L is relatively moved along the line along which the substrate should be cut 5 (in the direction of arrow A), so as to move the light-converging point P along the line along which the substrate should be cut 5. This forms the modified region 7 along the line along which the substrate should be cut 5 only within the substrate 1 as shown in FIGS. 3 to 5, and the modified region 7 forms a starting point region for cutting (part to cut) 8. In the laser processing method in accordance with this embodiment, no modified region 7 is formed upon heating the substrate 1 by causing the substrate 1 to absorb the laser light L. Instead, the laser light L is transmitted through the semiconductor substrate 1, so as to generate multiphoton absorption within the semiconductor substrate 1, thereby forming the modified region 7. Hence, the laser light L is hardly absorbed by the front

face 3 of the semiconductor substrate 1, whereby the front face 3 of the semiconductor substrate 1 does not melt.

If a start point exists at a location to cut when cutting the substrate 1, the substrate 1 fractures from this start point and thus can be cut with a relatively small force as shown in FIG. 6. This makes it possible to cut the substrate 1 without generating unnecessary fractures in the front face 3 of the substrate 1.

There seem to be the following two ways of cutting the substrate from the starting point region for cutting acting as a start point. The first case is where, after forming the starting point region for cutting, an artificial force is applied to the substrate, so that the substrate fractures from the starting point region for cutting acting as a start point, whereby the substrate is cut. This is the cutting in the case where the substrate has a large thickness, for example. The application of an artificial force encompasses application of bending stress and shearing stress along the starting point region for cutting of the substrate, and exertion of a temperature difference upon the substrate to generate thermal stress, for example. The other case is where a starting point region for cutting is formed, so that the substrate is naturally fractured in a cross-sectional direction (thickness direction) of the substrate from the starting point region for cutting acting as a start point, whereby the substrate is cut. This is enabled, for example, by forming the starting point region for cutting by a single row of modified regions when the substrate has a small thickness, and by a plurality of rows of modified regions aligned in the thickness direction when the substrate has a large thickness. Even in the case of natural fracturing, fractures do not extend to the front face at a location not formed with the starting point region for cutting in the part to cut, whereby only the part corresponding to the location formed with the starting point region for cutting can be fractured. Thus, fracturing can be regulated well. Such a fracturing method with favorable controllability is quite effective, since semiconductor substrates such as silicon wafers have recently been apt to become thinner.

The modified region formed by multiphoton absorption in this embodiment includes the following cases (1) to (3):

(1) Case where the Modified Region is a Crack Region Including One or a Plurality of Cracks

A substrate (e.g., glass or a piezoelectric material made of $LiTaO_3$) is irradiated with laser light while a light-converging point is positioned therewithin under a condition with an electric field intensity of at least 1×10^8 (W/cm^2) at the light-converging point and a pulse width of 1 μs or less. This pulse width is a condition under which a crack region can be formed only within the substrate while generating multiphoton absorption without causing unnecessary damages to the substrate. This generates a phenomenon of optical damage due to multiphoton absorption within the substrate. This optical damage induces thermal distortion within the substrate, thereby forming a crack region therewithin. The upper limit of electric field intensity is 1×10^{12} (W/cm^2), for example. The pulse width is preferably 1 ns to 200 ns, for example. The forming of a crack region due to multiphoton absorption is described, for example, in "Internal Marking of Glass Substrate by Solid-state Laser Harmonics", *Proceedings of 45th Laser Materials Processing Conference* (December 1998), pp. 23-28.

The inventors determined relationships between the electric field intensity and the magnitude of crack by an experiment. Conditions for the experiment are as follows:

(A) Substrate: Pyrex (registered trademark) glass (having a thickness of 700 μm)

(B) Laser

Light source: semiconductor laser pumping Nd:YAG laser

Wavelength: 1064 nm

Laser light spot cross-sectional area: $3.14 \times 10^{-8} \text{ cm}^2$

Oscillation mode: Q-switch pulse

Repetition frequency: 100 kHz

Pulse width: 30 ns

Output: output <1 mJ/pulse

Laser light quality: TEM_{00}

Polarization characteristic: linear polarization

(C) Light-converging lens

Transmittance with respect to laser light wavelength: 60%

(D) Moving speed of a mounting table mounting the substrate: 100 mm/sec

Here, the laser light quality being TEM_{00} indicates that the light convergence is so high that light can be converged up to about the wavelength of laser light.

FIG. 7 is a graph showing the results of the above-mentioned experiment. The abscissa indicates peak power density. Since laser light is pulse laser light, its electric field intensity is represented by the peak power density. The ordinate indicates the size of a crack part (crack spot) formed within the substrate processed by one pulse of laser light. Crack spots gather, so as to form a crack region. The size of a crack spot refers to that of the part of dimensions of the crack spot yielding the maximum length. The data indicated by black circles in the graph refers to a case where the light-converging lens (C) has a magnification of $\times 100$ and a numerical aperture (NA) of 0.80. On the other hand, the data indicated by white circles in the graph refers to a case where the light-converging lens (C) has a magnification of $\times 50$ and a numerical aperture (NA) of 0.55. It is seen that crack spots begin to occur within the substrate when the peak power density reaches about $10^{11} \text{ (W/cm}^2\text{)}$, and become greater as the peak power density increases.

A mechanism by which the substrate is cut upon formation of a crack region in the laser processing in accordance with this embodiment will now be explained with reference to FIGS. 8 to 11. As shown in FIG. 8, the substrate 1 is irradiated with laser light L while positioning the light-converging point P within the substrate 1 under a condition where multiphoton absorption occurs, so as to form a crack region 9 therewithin along a line along which the substrate should be cut. The crack region 9 is a region including one or a plurality of crack spots. The crack region 9 forms a starting point region for cutting. As shown in FIG. 9, the crack further grows while using the crack region 9 as a start point (i.e., using the starting point region for cutting as a start point). As shown in FIG. 10, the crack reaches the front face 3 and rear face 21 of the substrate 1. As shown in FIG. 11, the substrate 1 breaks, so as to be cut. The crack reaching the front face and rear face of the substrate may grow naturally or grow as a force is applied to the substrate.

(2) Case where the Modified Region is a Molten Processed Region

A substrate (e.g., a semiconductor material such as silicon) is irradiated with laser light while a light-converging point is positioned therewithin under a condition with an electric field intensity of at least $1 \times 10^8 \text{ (W/cm}^2\text{)}$ at the light-converging point and a pulse width of 1 μs or less. As a consequence, the inside of the substrate is locally heated by multiphoton absorption. This heating forms a molten processed region within the substrate. The molten processed region refers to a region once melted and then re-solidified,

a region just in a melted state, or a region in the process of re-solidifying from its melted state, and may also be defined as a phase-changed region or a region having changed its crystal structure. The molten processed region may also be regarded as a region in which a certain structure has changed into another structure in monocrystal, amorphous, and polycrystal structures. Namely, it refers to a region in which a monocrystal structure has changed into an amorphous structure, a region in which a monocrystal structure has changed into a polycrystal structure, and a region in which a monocrystal structure has changed into a structure including an amorphous structure and a polycrystal structure, for example. When the substrate is a silicon monocrystal structure, the molten processed region is an amorphous silicon structure, for example. The upper limit of electric field intensity is $1 \times 10^{12} \text{ (W/cm}^2\text{)}$, for example. The pulse width is preferably 1 ns to 200 ns, for example.

By an experiment, the inventors have verified that a molten processed region is formed within a silicon wafer. Conditions for the experiment are as follows:

(A) Substrate: silicon wafer (having a thickness of 350 μm and an outer diameter of 4 inches)

(B) Laser

Light source: semiconductor laser pumping Nd:YAG laser

Wavelength: 1064 nm

Laser light spot cross-sectional area: $3.14 \times 10^{-8} \text{ cm}^2$

Oscillation mode: Q-switch pulse

Repetition frequency: 100 kHz

Pulse width: 30 ns

Output: 20 $\mu\text{J/pulse}$

Laser light quality: TEM_{00}

Polarization characteristic: linear polarization

(C) Light-converging lens

Magnification: $\times 50$

N. A.: 0.55

Transmittance with respect to laser light wavelength: 60%

(D) Moving speed of a mounting table mounting the substrate: 100 mm/sec

FIG. 12 is a view showing a photograph of a cut section in a part of a silicon wafer cut by laser processing under the above-mentioned conditions. A molten processed region 13 is formed within a silicon wafer 11. The size of the molten processed region 13 formed under the above-mentioned conditions is about 100 μm in the thickness direction.

The fact that the molten processed region 13 is formed by multiphoton absorption will now be explained. FIG. 13 is a graph showing relationships between the wavelength of laser light and the transmittance within the silicon substrate. Here, respective reflecting components on the front face side and rear face side of the silicon substrate are eliminated, whereby only the transmittance therewithin is represented. The above-mentioned relationships are shown in the cases where the thickness t of the silicon substrate is 50 μm , 100 μm , 200 μm , 500 μm , and 1000 μm , respectively.

For example, it is seen that laser light transmits through the silicon substrate by at least 80% at 1064 nm, where the wavelength of Nd:YAG laser is located, when the silicon substrate has a thickness of 500 μm or less. Since the silicon wafer 11 shown in FIG. 12 has a thickness of 350 μm , the molten processed region 13 due to multiphoton absorption is formed near the center of the silicon wafer, i.e., at a part separated from the front face by 175 μm . The transmittance in this case is 90% or greater with reference to a silicon wafer having a thickness of 200 μm , whereby the laser light is absorbed within the silicon wafer 11 only slightly and is substantially transmitted therethrough. This means that the

molten processed region **13** is not formed by laser light absorption within the silicon wafer **11** (i.e., not formed upon usual heating with laser light), but by multiphoton absorption. The forming of a molten processed region by multiphoton absorption is described, for example, in “Processing Characteristic Evaluation of Silicon by Picosecond Pulse Laser”, *Preprints of the National Meeting of Japan Welding Society*, No. 66 (April 2000), pp. 72-73.

Here, a fracture is generated in the cross-sectional direction while using a molten processed region as a start point, whereby the silicon wafer is cut when the fracture reaches the front face and rear face of the silicon wafer. The fracture reaching the front face and rear face of the silicon wafer may grow naturally or grow as a force is applied to the silicon wafer. The fracture naturally grows from the starting point region for cutting to the front face and rear face of the silicon wafer in any of the cases where the fracture grows from the molten processed region in a melted state and where the fracture grows from the molten processed region in the process of re-solidifying from the melted state. In any of these cases, the molten processed region is formed only within the silicon wafer. In the cut section after cutting, the molten processed region is formed only therewithin as shown in FIG. 12. When a molten processed region is formed within the substrate, unnecessary fractures deviating from a line along which the substrate should be cut are hard to occur at the time of fracturing, which makes it easier to control the fracturing.

(3) Case where the Modified Region is a Refractive Index Change Region

A substrate (e.g., glass) is irradiated with laser light while a light-converging point is positioned therewithin under a condition with an electric field intensity of at least 1×10^8 (W/cm²) at the light-converging point and a pulse width of 1 ns or less. When multiphoton absorption is generated within the substrate with a very short pulse width, the energy caused by multiphoton absorption is not transformed into thermal energy, so that a permanent structural change such as ionic valence change, crystallization, or polarization orientation is induced within the substrate, whereby a refractive index change region is formed. The upper limit of electric field intensity is 1×10^{12} (W/cm²), for example. The pulse width is preferably 1 ns or less, more preferably 1 ps or less, for example. The forming of a refractive index change region by multiphoton absorption is described, for example, in “Formation of Photoinduced Structure within Glass by Femtosecond Laser Irradiation”, *Proceedings of 42th Laser Materials Processing Conference* (November 1997), pp. 105-111.

The cases of (1) to (3) are explained as modified regions formed by multiphoton absorption in the foregoing. When a starting point region for cutting is formed as follows in view of the crystal structure of the substrate, the cleavage property thereof, and the like, the substrate can be cut with a smaller force and a higher accuracy while using the starting point region for cutting as a start point.

Namely, in the case of a substrate made of a monocrystal semiconductor having a diamond structure such as silicon, the starting point region for cutting is preferably formed in a direction along the (111) plane (first cleavage plane) or (110) plane (second cleavage plane). In the case of a substrate made of a III-V family compound semiconductor having a zinc ore type structure such as GaAs, the starting point region for cutting is preferably formed in a direction along the (110) plane. In the case of a substrate having a hexagonal crystal structure such as sapphire (Al₂O₃), a starting point region for cutting is preferably formed in a

direction along the (1120) plane (A plane) or (1100) plane (M plane) while using the (0001) plane (C plane) as a principal plane.

When the substrate is formed with an orientation flat along a direction to be formed with the starting point region for cutting (e.g., in a direction along the (111) plane in the monocrystal silicon substrate) or a direction orthogonal to the direction to be formed with the starting point region for cutting, the starting point region for cutting extending along the direction to be formed with the starting point region for cutting can be formed in the substrate in an easy and accurate manner with reference to the orientation flat.

In the following, the present invention will be explained more specifically with reference to Examples.

Example 1

Example 1 of the substrate dividing method in accordance with the present invention will now be explained. Example 1 is directed to a case where the substrate **1** is a silicon wafer (having a thickness of 350 μm and an outer diameter of 4 inches) (“substrate **1**” will hereinafter be referred to as “semiconductor substrate **1**” in Example 1), whereas the front face **3** of the semiconductor substrate **1** is formed with a plurality of functional devices in a device manufacturing process.

First, before explaining a step of forming a starting point region for cutting within the semiconductor substrate **1**, a laser processing apparatus employed in the step of forming a starting point region for cutting will be explained with reference to FIG. 14. FIG. 14 is a schematic diagram of the laser processing apparatus **100**.

The laser processing apparatus **100** comprises a laser light source **101** for generating laser light L; a laser light source controller **102** for controlling the laser light source **101** so as to regulate the output, pulse width, etc. of laser light L and the like; a dichroic mirror **103**, arranged so as to change the orientation of the optical axis of laser light L by 90°, having a function of reflecting the laser light L; a light-converging lens **105** for converging the laser light L reflected by the dichroic mirror **103**; a mounting table **107** for mounting a semiconductor substrate **1** irradiated with the laser light L converged by the light-converging lens **105**; an X-axis stage **109** for moving the mounting table **107** in the X-axis direction; a Y-axis stage **111** for moving the mounting table **107** in the Y-axis direction orthogonal to the X-axis direction; a Z-axis stage **113** for moving the mounting table **107** in the Z-axis direction orthogonal to the X- and Y-axis directions; and a stage controller **115** for controlling the movement of these three stages **109**, **111**, **113**.

The Z-axis direction is a direction orthogonal to the front face **3** of the semiconductor substrate **1**, and thus becomes the direction of focal depth of laser light L incident on the semiconductor substrate **1**. Therefore, moving the Z-axis stage **113** in the Z-axis direction can position the light-converging point P of laser light L within the semiconductor substrate **1**. This movement of light-converging point P in X(Y)-axis direction is effected by moving the semiconductor substrate **1** in the X(Y)-axis direction by the X(Y)-axis stage **109** (**111**).

The laser light source **101** is an Nd:YAG laser generating pulse laser light. Known as other kinds of laser usable as the laser light source **101** include Nd:YVO₄ laser, Nd:YLF laser, and titanium sapphire laser. For forming a molten processed region, Nd:YAG laser, Nd:YVO₄ laser, and Nd:YLF laser are preferably employed. Though pulse laser light is used for processing the semiconductor substrate **1** in Example 1,

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8. A semiconductor chip manufacturing method according to claim 1, further comprising expanding a tape attached to the rear face of the substrate after the grinding to make space between adjacent chips formed in the substrate.

9. A semiconductor chip manufacturing method according to claim 1, further comprising attaching a tape to the rear face of the substrate after the grinding.

10. A semiconductor chip manufacturing method according to claim 1, wherein at the completion of the grinding, each fracture reaches the front face and the rear face of the substrate to divide the substrate.

11. A semiconductor chip manufacturing method comprising the steps of:

irradiating a laser light incident face of a substrate with laser light while positioning a light-converging point within the substrate, thereby forming a plurality of rows of molten processed regions aligned in a thickness direction of the substrate and embedded within the substrate along each line of a plurality of cutting lines arranged in a grid with respect to the substrate, the substrate having a front face and a rear face, the front face of the substrate being formed with at least one functional device, the forming of each molten processed region resulting in the forming of each starting point region configured for cutting the substrate, and each molten processed region being located inside the substrate at a predetermined distance from the laser light incident face of the substrate; and

grinding the rear face of the substrate after the forming of the starting point regions, thereby removing from the substrate at least a portion of the molten processed regions that were formed in the substrate;

wherein a fracture generated in the thickness direction from each starting point region reaches at least the front face of the substrate, thereby providing at least one semiconductor chip.

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12. A semiconductor chip manufacturing method according to claim 11, wherein when each molten processed region is formed in the substrate by the irradiating, the substrate is irradiated with the laser light under a condition with a peak power density of at least 1×10^8 (W/cm²) at the light converging point and a pulse width of 1 μ s or less.

13. A semiconductor chip manufacturing method according to claim 11, wherein the laser light incident face of the substrate is formed to include the functional device.

14. A semiconductor chip manufacturing method according to claim 11, wherein the grinding step includes a step of subjecting the rear face of the substrate to chemical etching.

15. A semiconductor chip manufacturing method according to claim 11, wherein the substrate is divided into a plurality of chips along the cutting lines.

16. A semiconductor chip manufacturing method according to claim 11, wherein the substrate is divided when each fracture reaches the front face and the rear face of the substrate after the step of grinding.

17. A semiconductor chip manufacturing method according to claim 11, wherein the substrate is divided when each fracture reaches the front face and the rear face of the substrate during the step of grinding the substrate.

18. A method of manufacturing, a semiconductor device according to claim 11, further comprising expanding a tape attached to the rear face of the substrate after the grinding to make space between adjacent chips formed in the substrate.

19. A method of manufacturing a semiconductor device according to claim 11, further comprising attaching a tape to the rear face of the substrate after the grinding.

20. A method of manufacturing a semiconductor device according to claim 11, wherein at the completion of the grinding, each fracture reaches the front face and the rear face of the substrate to divide the substrate.

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